Grounding language in the neglected senses of touch, taste, and smell

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ABSTRACT

Grounded theories hold sensorimotor activation is critical to language processing. Such theories have focused predominantly on the dominant senses of sight and hearing. Relatively fewer studies have assessed mental simulation within touch, taste, and smell, even though they are critically implicated in communication for important domains, such as health and wellbeing. We review work that sheds light on whether perceptual activation from lesser studied modalities contribute to meaning in language. We critically evaluate data from behavioural, imaging, and cross-cultural studies. We conclude that evidence for sensorimotor simulation in touch, taste, and smell is weak. Comprehending language related to these senses may instead rely on simulation of emotion, as well as crossmodal simulation of the "higher" senses of vision and audition. Overall, the data suggest the need for a refinement of embodiment theories, as not all sensory modalities provide equally strong evidence for mental simulation.

1. Introduction

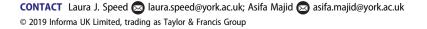We live in a rich, multimodal world, and language is a vehicle to convey our experiences to others. But what is the precise relationship between language and the senses such that we can understand each other? In recent decades, a wealth of evidence has emerged supporting a role for the sensorimotor systems in language comprehension: conceptual processing recruits (is grounded or embodied in) systems involved in perception and action (neural reuse; Anderson, 2010; Barsalou, 2016). The activation of these systems during language comprehension is referred to as "mental simulation" (e.g., Zwaan, 2003). Numerous studies provide evidence against the idea that meaning is composed exclusively of abstract, arbitrary, amodal symbols. It has been shown, for example, that passively listening to words depicting upward or downward motion (e.g., *fly, dive*) interferes with low-level detection of motion in an incongruent direction (Meteyard, Zokaei, Bahrami, & Vigliocco, 2008). Nevertheless, the extent to which language is grounded in the senses is still hotly debated (see Barsalou, 2016; Bedny & Caramazza, 2011; Caramazza, Anzellotti, Strnad, & Lingnau, 2014; Louwerse, 2011; Mahon & Caramazza, 2008; Pulvermüller, 2013).

One limitation of existing research is that it has focused heavily on the dominant systems of vision, audition, and action. We know, for example, that language conveying visual properties can activate the visual system (Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995; Pulvermuller & Hauk, 2006; Simmons et al., 2007). Likewise, behavioural experiments show that when reading words and sentences, we visually represent the shape of the objects depicted (Zwaan et al., 2017; Zwaan, Stanfield, & Yaxley, 2002), direction of motion (Kaschak et al., 2005; Meteyard, Bahrami, & Vigliocco, 2007; Meteyard et al., 2008; Zwaan, Madden, Yaxley, & Aveyard, 2004), and visibility (Yaxley & Zwaan, 2007). There is similar evidence that the motor system can be activated by language in a somatotopic manner (Hauk, Johnsrude, & Pulvermüller, 2004; Tettamanti et al., 2005), and that language activates representations of actions with specific direction (Glenberg & Kaschak, 2002; Rueschemeyer, Pfeiffer, & Bekkering, 2010), handshape (Wheeler & Bergen, 2010), and grasp (Tucker & Ellis, 2004; Zwaan & Taylor, 2006). Although the generalizability of these findings is contested (see, e.g., Chao & Martin, 1999; Lebois, Wilson-Mendenhall, & Barsalou, 2015; Morey, Glenberg, Kaschak, Lakens, & Zwaan, 2018; Ostarek, Joosen, Ishag, de Nijs, & Huettig,

2019), the accumulated evidence suggests that under the right circumstances (see Yee & Thompson-Schill, 2016) language can activate vision, audition, and action systems, and that it can do so in a specific and fine-grained manner.

However, there is more to sensorimotor experience than this. The perceptual system has traditionally been portrayed as a five-sense system, which aside from vision and audition, includes touch, taste, and smell (the Aristotelian model, Sorabji, 1971; but see Winter, 2019, on the continuity of the senses). Of course, there are ways to conceive of the senses other than by appeal to canonical sense organs (i.e., perceived by the eyes, ears, hands, mouth, or nose). At one extreme, we could enumerate sensory modalities by stimulus type, and thus distinguish three: light (vision), mechanical (touch, hearing), and chemical (smell, taste) senses. At the other end, we could base our classification on receptor types leading to more than 30 distinct "senses" (O'Meara, Speed, San Roque, & Majid, 2019). For the purposes of this review, we merely seek to draw attention to the fact that very little research has gone beyond the well-trodden senses of vision and audition in order to consider whether language interacts with other sensory modalities. In particular, we ask whether language recruits the same sensory representations as used in the perception of touch, taste, and smell—the so-called "lower" senses (Classen, 1997; Howes, 2003). If these senses contribute to everyday experience, then according to grounded theories, they should be recruited for language comprehension too.

Historically, comparatively less was known about the perceptual systems involved in touch, taste, and smell, than vision and audition, making it difficult to predict in what way language would interact with these systems precisely (see also Levinson & Majid, 2014). Earlier studies suggested the lower senses were not as reliable. For example, people have more difficulty shifting attention away from the tactile modality to another modality than from the auditory or visual modality to a different modality (Spence, Nicholls, & Driver, 2001a; Spence, Shore, & Klein, 2001b), and when people judge the distance between two points using touch they generally underestimate, whereas judgment based on vision is relatively accurate (Stevens, 1975; Gescheider, 1997). Touch is also difficult to define precisely, referred to as "a rag-bag sense that scatters in many sub-senses" (de Vignemont & Massin, 2015, p. 3).

Taste also has complexities. Here it is important to make a distinction between taste proper and flavour (Spence, Smith, & Auvray, 2015), with flavour being the multisensory combination of taste, odour, texture, temperature, and trigeminal sensation (Auvray & Spence, 2008). Whether or not taste should be considered a separate modality or a sub-component of flavour is debated (Spence et al., 2015). It is thought to be difficult to imagine tastes (Andrade, May, Deeprose, Baugh, & Ganis, 2014), and problems can arise when identifying them too (e.g., O'Mahony, Goldenberg, Stedmon, & Alford, 1979).

Our sense of smell too has been regularly underestimated (Classen, Howes, & Synnott, 1994); although new evidence suggests we may be better at detecting and discriminating odours than once thought (Bushdid, Magnasco, Vosshall, & Keller, 2014; Majid, Speed, Croijmans, & Arshamian, 2017; Shepherd, 2004), the consensus remains that we struggle to identify odours, with some estimates claiming we can correctly name less than half of the everyday odours we encounter (Cain, 1979). This may be because odour and language are weakly connected in the brain (Engen, 1987; Lorig, 1999; Olofsson & Gott-fried, 2015). Like taste, it is also comparably difficult to imagine an odour (Arshamian & Larsson, 2014), suggesting people have difficulty accessing olfactory representations in the absence of a real odour.

At the same time, the lower senses appear to be poorly elaborated in language (Buck, 1949; Levinson & Majid, 2014), further bolstering the idea that these senses are not so important in modern life. Talk about vision outstrips talk about the other senses in everyday conversation (San Roque et al., 2015; Winter, Perlman, & Majid, 2018), and there appear to be few dedicated resources for depicting the qualities of touch, taste, and smell. Take smell—in Western languages, it is claimed we lack vocabulary to convey our experience of odours; cf. Ackerman (1990, p.6): "Smell is the mute sense, the one without words". The paucity of dedicated vocabulary does not leave us completely mute, however. When pressed to talk about odours, we do so in terms of their source (e.g., *it smells like cinnamon*), or valence (e.g., *that smells disgusting*), or we use crossmodal metaphors (e.g., *heavy*; Iatropoulos et al., 2018). The case for taste is marginally better, where cross-linguistic data from across the world appear to agree on the basic distinctions of sweet, salty, bitter, and sour

(Chamberlain, 1903; Majid & Levinson, 2008; Myers, 1904), although confusions are made when identifying basic tastes (O'Mahony et al., 1979), and lexical conflations across tastes exist (the same term being used to describe sour and bitter, for example) (Majid & Levinson, 2008). Flavour language does extend beyond the basic tastes, but this lexicon has also been described as limited (Magee, 2009).

If we look beyond the West however, the purported limits on language for the lower senses reveal themselves to be culture-bound (Majid, Burenhult, Stensmyr, de Valk, & Hansson, 2018), supporting the idea that language for the lower senses needs a thorough re-examination. As an example, there are numerous hunter-gatherer communities that possess elaborate odour lexicons (Hombert, 1992; Majid & Burenhult, 2014; Majid & Kruspe, 2018; Majid et al., 2018; O'Meara & Majid, 2016; Wnuk & Majid, 2014). Similarly, taste and texture appear to be richly encoded in other parts of the world (Backhouse, 1994; Dingemanse & Majid, 2012; Nakagawa, 2012; Osawa & Ellen, 2014). Such facts challenge our traditional assumptions about the senses, and suggest the scientific community could look quite different if the scope of work was widened to include cross-linguistic facts (Kemmerer, 2019; Levinson, 2012).

More generally, an examination of the lower senses is timely, as there is accumulating evidence for the importance of these senses in all our lives. We rely on the language of touch to convey our sense of comfort or pain (e.g., Melzack, 1975), and miscommunication can be harmful (Wierzbicka, 2012). Taste and smell are crucially intertwined with our consumption of food and drinks, which has important implications for our health (Boesveldt & de Graaf, 2017). Nowadays, appetite control and obesity are serious issues, and language may play a crucial role in its management. Smell also plays a critical role in hygiene and personal relationships (Semin & de Groot, 2013): people desire to smell good, and have pleasant smelling homes. Beyond personal well-being, the language of the lower senses is important in advertising with marketers eager to learn how best to use language to sell their products (e.g., food, perfume).

In this article, our aim is to assess whether language related to the lower senses activates corresponding perceptual systems. We review research specifically investigating the grounding of word meaning in touch, taste, and smell. Before turning to the critical evidence, we first highlight some crucial issues in research on grounded language.

2. Ongoing debates in grounded language research

We see two key issues present in the grounded language debate, and we focus on these in this review: automaticity and specificity of mental simulation. First, by automaticity we mean whether or not mental simulations that are observed occur inevitably during language comprehension, or instead arise from other processes—such as strategic mental imagery. Although some argue that mental simulation and mental imagery overlap—at least in part—here we consider how automatic the activation of the relevant perceptual system is when understanding language. For example, if perceptual systems are activated quickly and without volition during language comprehension, we call this "mental simulation", whereas if perceptual systems are only activated upon strategic, conscious deliberation, we call this "mental imagery" (Pecher, van Dantzig, & Schifferstein, 2009; Willems, Toni, Hagoort, & Casasanto, 2010; Zwaan & Pecher, 2012; but note that mental imagery could still be in line with weaker versions of embodiment such as "secondary embodiment", see Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012). Evidence for automatic activation would include engagement of perceptual representations during language processing at short time-scales (e.g., Hauk & Pulvermüller, 2004; Kiefer, Sim, Herrnberger, Grothe, & Hoenig, 2008; Wheatley, Weisberg, Beauchamp, & Martin, 2005), or during tasks that are unrelated to the domain of interest, such as lexical decision, where a judgment is made about whether an item is a real-word or not, rather than a judgment about a specific aspect of the word's meaning (e.g., Meteyard et al., 2008). In contrast, tasks that require deliberate decision-making related to the domain of interest, or that are at such a time scale that rumination about the words is possible, could instead be explained as the result of strategic mental imagery (e.g., see de la Vega, de Filippis, Lachmair, Dudschig, & Kaup, 2012; Lebois et al., 2015).

The second issue is specificity: at what level of detail are sensory activations being engaged during mental simulation? Simulations can be coarse-grained, in which experiential details are coded in a schematic

and abstract manner (Barsalou, 1999, 2003; Zwaan, 2003). Alternatively, simulations could be detailed, as is seen for action language where representations of specific effectors are activated by language (Hauk et al., 2004; Tettamanti et al., 2005), and fine-grained action dynamics are represented (Desai, Herter, Riccardi, Rorden, & Fridriksson, 2015; Speed, van Dam, Vigliocco, & Desai, 2018).

Specificity can be assessed using words or sentences that vary on particular dimensions, such as direction (e.g., Kaschak, Zwaan, Aveyard, & Yaxley, 2006; Meteyard et al., 2007), or speed of motion (e.g., Speed et al., 2018; Speed & Vigliocco, 2014). For example, listening to sentences describing slow motion leads to longer mental simulations than sentences describing fast motion. This suggests that motion simulations include specific details about speed of motion (Speed & Vigliocco, 2014).

Another way researchers have assessed specificity is to examine whether regions of the brain activated by language overlap with regions responsive to the same real-world sensorimotor experience. For example, words describing actions performed with the body have been found to activate primary motor cortex (Hauk et al., 2004), and words for objects with acoustic properties have been found to activate regions of auditory association cortex that are also activated by real-world sounds (Kiefer et al., 2008), suggesting a close correspondence between real-world sensorimotor experience and language processing. Furthermore, the location of the activation can, in principle, shed light on the nature of the mental simulation. Hauk et al. (2004) found detailed simulation with somatotopic activation of the motor system (see also Tettamanti et al., 2005), thereby demonstrating specific effectors can be represented in language comprehension. Other work suggests more schematic simulations: Pulvermuller and Hauk (2006) found that words related to colour activated anterior regions of the visual system which are thought to process colour knowledge—rather than low-level visual information per se—suggesting colour simulations may be more abstracted than real-world visual perception (see also Simmons et al., 2007).

Although the use of fMRI is prevalent as a means for uncovering the type of representation implicated in language comprehension, this line of work relies on informal reverse inference—that is, inferring a particular sensory or motor process is engaged based on patterns of activation of a specific brain region. This can be problematic if the brain to function mapping is multifold—i.e., the same brain region is implicated in multiple cognitive processes—and if the region can be activated in a non-specific manner with regards to sensory modality (Aguirre, 2003; Poldrack, 2006; Poldrack, 2011; Smeets et al., 2019). We will see this limitation affects the interpretation of a number of studies investigating touch, taste, and smell. Another general problem concerning imaging studies, also relevant to our interpretation of findings here, is the widespread use of small sample sizes and concomitant lack of statistical power (Smeets et al., 2019; Turner, Paul, Miller, & Barbey, 2018). On the one hand, small sample sizes could mean the literature is simply not finding existent effects; on the other hand, reported findings may be false positives. Keeping these caveats in mind, we nevertheless review the fMRI literature in order to take stock of the field at this moment.

Our main goal is to assess the extent to which the lower senses are activated automatically during language comprehension, and to determine what level of specificity they can be activated—if at all. It is possible that these senses are not activated automatically, since they are said to be less reliable. In addition, any activation from language may be more schematic than detailed as the lower senses are not as elaborated lexically. At the same time, these senses have vital functions in everyday life, so automatic and specific activation could be as critical as for sight and hearing.

To foreshadow the argument that is to follow, we conclude that the research to date has not provided convincing evidence that the lower senses are activated in an automatic manner. Moreover, the evidence leads us to conclude that grounding in touch, taste, and smell, may be more limited and abstracted in comparison to vision and audition (at least in English and related languages). We discuss the possibility that understanding language for the lower senses may, in fact, rely on grounding in other sensory modalities or emotional experiences—what we call "crossmodal compensation"—and consequently, the particulars of the grounding of language is heterogeneous across the senses.

3. The current review

The present paper reviews both behavioural and neuroimaging research with the view to establishing

whether language related to the sense of touch, taste, and smell, is represented (at least in part) through activation of perceptual representations of these modalities. Given the paucity of vocabulary alluded to in the introduction for these modalities—at least in English where the majority (not all) of the experimental work has been conducted—this requires further unpacking. In the context of this review, we examine the meaning of words that refer to objects or experiences primarily experienced through the perceptual modalities of touch, taste, or smell. This could include words where the sensory modality is necessarily encapsulated in a term's meaning (the verbs *to taste* or *to smell*, for example), but also language where there is a strong association with the sensory modalities of interest. There are adjectives that pick out qualities related to an experience of touch, taste, or smell (e.g., *hot*, *sour, stinky*); as well as nouns (e.g., *sandpaper*, *sugar*, *perfume*) and verbs with comparable associations (e.g., *grope, eat, breathe*; Winter, 2016). Sensory experience is relevant to all word meanings related to perceptual experiences, but potentially to different degrees. For example, nouns are found to be more multimodal than adjectives in English (Lynott & Connell, 2009, 2013).

One method to establish the sensory associations of words is to collect "modality exclusivity ratings". For example, Lynott and Connell (2009, 2013) asked English speakers to rate adjectives and nouns for how much a word's referent could be experienced through each of the five modalities of sight, hearing, touch, taste, and smell. Having separate scales for each perceptual modality meant that participants did not have to categorize a word into a single modality, so the degree to which a word was multimodal could also be established. Based on such ratings, individual words were then classified by their dominant modality, as well as their "modality exclusivity", i.e., the extent to which the word is multimodal or unimodal.

In addition to their utility in stimuli selection, such ratings are informative about the role of the perceptual modalities in word meaning. For example, olfaction and gustation are typically found to be the weakest modalities, and vision the strongest in both English and Dutch (Lynott & Connell, 2009, 2013; Speed & Majid, 2017a; Winter, 2016; Winter et al., 2018; but see Chen, Zhao, Long, Lu, & Huang, 2019, where the auditory modality was rated lower than

the gustatory modality in Mandarin Chinese). This is the case even when the item set is purposefully chosen so that each of the five perceptual modalities are well represented (Speed & Majid, 2017a). The ratings also reveal the role of multimodal perception in concept representation: ratings of olfaction correlate with those of gustation, reflecting their interaction in flavour perception; and ratings of touch correlate with vision, reflecting how objects we physically act on can usually also be seen (Lynott & Connell, 2009, 2013; Speed & Majid, 2017a).

So although English, and other Standard Average European languages, may have few words that specifically describe touch, taste, and smell experiences, there are clearly many word meanings for which these modalities are important. As mentioned previously, touch, taste, and smell experiences play a fundamental role in everyday life, so it is important to understand how language for these modalities is processed and represented. The theoretical and applied implications are profound. To this end we assess studies that explicitly test grounded accounts of language related to the "lower" senses, as well as other studies that speak to the issue but were not explicitly designed for this purpose.

We begin with touch, possibly the most concrete of the three modalities since it, in general, involves contact between the body and an object. We then move onto the chemical senses beginning with the complex modality of taste, before tackling the more elusive sense of smell.

4. Touch

Broadly, touch can be defined as awareness of the body in space, although it is generally acknowledged to be a difficult modality to characterize (de Vignemont & Massin, 2015). As a consequence, we consider this sense in terms of several distinct components. We focus on a few different topics that have been investigated separately in the literature, but it behooves us to point out that there are others just as worthy of investigation, for example, proprioception, vibration, and kinaesthesia. Our focus here is a result of the current state-of-the-art in the language of touch from a grounded perspective. We focus on experiences related to tactile sensing (e.g., roughness, hardness), temperature (i.e., experiences of heat), pain (sensory and affective aspects of painful stimuli), and we also

briefly consider the language of interoception—another type of sensing with the body (although not technically a component of touch).

4.1. Tactile

Tactile-related words tend to be more iconic—i.e., they sound like what they mean (e.g., *crisp*)—than words related to taste, smell, or even sight (Winter, Perlman, Perry, & Lupyan, 2017). Since iconicity may be a bridge to embodiment (Perniss & Vigliocco, 2014), tactile-related language may be strongly related to mental simulation. Tactile simulation during language comprehension has been demonstrated in behavioural experiments. As mentioned in the introduction, tactile stimuli are typically more difficult to shift attention away from than visual and auditory stimuli (Spence et al., 2001a, 2001b). This asymmetry appears to be reflected in language processing too. Connell and Lynott (2010) gave participants words for object properties (e.g., *chilly*, *silky*), and asked them to decide whether the word matched a target modality (auditory, gustatory, tactile, olfactory, visual). Responses were less accurate for tactile judgments compared to the other modalities. This effect was found even when words were presented for only 17ms—ostensibly before conscious processing—suggesting an automatic effect. The fact that tactile judgments for words were disadvantaged in the same way that tactile judgments for perceptual stimuli has been interpreted as evidence that the meaning of tactile-related words includes tactile perceptual representations (Connell & Lynott, 2010). Although the results are certainly consistent with this interpretation, the judgments required people to explicitly judge whether words matched the target modality, so are likely to have activated the perceptual system more than during typical word comprehension.

In a different line of work exploiting a congruency paradigm, Brunyé et al. (2012) report behavioural evidence of tactile simulation during sentence comprehension. Participants read sentences that described a tactile or non-tactile experience and then felt and rated fabric samples. Sentences describing tactile experiences were either fabric-related (e.g., *Candice tied a long silk ribbon onto each of her wrapped gifts*), or fabric-unrelated (e.g., *Karen touched the grainy sandpaper*) describing either smooth, medium, or rough textures. For tactile sentences unrelated to fabric, all fabrics were rated rougher after rough sentences and smoother following smooth sentences. But for tactile sentences related to fabric, there was a specific congruency effect instead: after reading a smooth sentence, fabrics were only rated smoother if the fabric itself was smooth; and the same for rough sentences accompanied with rough fabrics. The results are consistent with the idea that language can lead to tactile simulations. Since the results for fabric-related and fabric-unrelated sentences differed, this suggests these simulations can be broad (a general representation of smoothness) or specific (a representation of smooth silk specifically) depending on context. Sadly, the study cannot speak to the automaticity of this effect. It is unclear what exactly the participants were told about the link between the sentences and the fabric-rating task, and whether or not they were aware of the aims of the study. A skeptic could argue that since the task involved texture rating, the reference to texture in the sentences was more explicitly brought to mind.

Instead of assessing the effect of tactile-related language on tactile judgments, Connell, Lynott, and Dreyer (2012) tested the effect of tactile stimulation on semantic processing of tactile-related language. Participants made size judgments (*which is bigger/smaller?*) on pairs of words denoting objects (e.g., *coin* vs. *frisbee*) whilst receiving tactile stimulation on their hands (or feet as a control) via vibrating cushions. Size judgments were facilitated during hand stimulation compared to foot stimulation. Crucially, this was only found for small manipulable objects (e.g., *coin*), but not larger, non-manipulable objects (e.g., *car*). This is evidence that tactile perception is relevant for processing the meaning of such words, and that it can play a functional role in word meaning. Since responses (i.e., judgments of size) were produced vocally, the effects cannot be the result of planning a response with the implied effector. As with the studies above, however, we cannot tell whether tactile perception is typically activated when merely comprehending these words, or whether the results are due to explicitly imagining the size of the depicted objects. Moreover, because of the perceptual dominance of vision (Stokes & Biggs, 2014), we would expect visual imagery alone would be enough to make size judgments, with tactile imagery being unnecessary. However, the fact that we do see an

effect of tactile stimulation during a task that could be completed using only visual imagery may suggest then that tactile simulation did occur automatically.

Another piece of evidence concerning whether tactile perception is involved in processing tactile language comes from the "modality-switch paradigm" as used by van Dantzig, Pecher, Zeelenberg, and Barsalou (2008). In their study, participants engaged in a perceptual detection task where they had to decide whether a flash of light, a tone, or a vibration on the finger occurred on the left or right. Following this, participants made property-verification judgments using a foot pedal for sentences describing auditory, visual, or tactile properties (e.g., *a coin is hard*). Overall, property-verification judgements were faster when the preceding perceptual stimulation matched the perceptual modality in the sentence (i.e., faster to respond to *a coin is hard* after tactile stimulation than after visual or auditory stimulation), consistent with the claim that language recruits tactile representations for tactile-related language. However, in their study van Dantzig and colleagues collapsed responses across all trials (visual, auditory, and tactile), making it impossible to ascertain whether or not the effect occurred within each specific modality. On reanalyzing the data, we found facilitation for auditory and visual concept-property pairs in same modality trials, but not tactile concept-property pairs.[1] In a similar study, participants made property judgments for target concept-property pairs (e.g., *apple-green*) following a context pair from the same or different modality (visual, auditory, and tactile; Pecher et al., 2009). Again, there were overall slower response times when the property judgment followed a prime in a different modality. But here too upon reanalyzing the data, the effect was only apparent for a subset of the conditions: in particular auditory concept-property targets, but not visual or tactile targets.[2] So, in actual fact, the modality-switch paradigm does not provide evidence in favour of tactile simulation. In sum, the behavioural evidence to date does not provide decisive evidence in favour of tactile perception being automatically activated during language comprehension.

Evidence from a different line of research, however, suggests perceptual activations related to textural metaphors can affect behaviour, even when the metaphor is not explicitly used (for review see Lee, 2016), suggesting an automatic link between texture perception and texture metaphor. People have been shown to negotiate more strongly and assign crimes harsher sentences after sitting on a hard seat rather than a soft seat (Ackerman, Nocera, & Bargh, 2010; Schaefer et al., 2018), consistent with metaphors such as "taking a hard line" or "being hard on crime". Similarly, touching a rough texture can make social interactions appear more harsh, difficult, and adversarial than touching a smooth texture (Ackerman et al., 2010; Schaefer, Denke, Heinze, & Rotte, 2014; cf. "having a rough day"), and holding something heavy rather than light can lead to judgments that things are more important and serious (Ackerman et al., 2010; cf. "thinking about weighty matters"). Such metaphors can also affect cognitive processes, so sitting on a hard surface is said to improve memory (being "rigid") while sitting on a soft surface improves creativity (being "flexible"; Xie, Lu, Wang, & Cai, 2016). For these studies, texture experience appears to affect cognition and behaviour even though texture is irrelevant for the situation.

One could criticize such experiments for being transparent in terms of the goals of the study (e.g., touching something, then judging a scenario). However, the study design relies on a between-participants manipulation; so, for example, people were not aware that their seat was harder or softer than another. Similarly, in Schaefer et al. (2014) people were told they were taking part in two separate experiments, and no-one reported being suspicious about a connection between the two studies—although it is not clear exactly how this information was probed. The effects reported also cannot be explained simply by the influence of valence, i.e., sitting uncomfortably makes you behave less favourably in general, as participant ratings of valence did not predict punishment harshness (Schaefer et al., 2018). Overall, these studies suggest some link between tactile experience and behaviour, but do not speak directly to the issue of tactile simulation during language comprehension.

Taken together, then, the behavioural evidence provides some nascent data in support of tactile activations being relevant for language processing, but none of the studies are conclusive on their own. Brain imaging data provides ancillary evidence. For example, judging whether a concrete word has a specific touch property (e.g., *soft*) activates the somatosensory cortex (relevant for tactile object recognition), as well as motor and premotor regions

(Goldberg, Perfetti, & Schneider, 2006b). But this task focuses on explicit judgments of texture, so we cannot determine whether this activation is automatic, or generated via strategic mental imagery. A different study found simply reading texture language activates texture-selective somatosensory cortex when it is used metaphorically (e.g., *she had a rough day*) compared to literal sentences with the same meaning (e.g., *she had a bad day*; Lacey, Stilla, & Sathian, 2012). Finally, making similarity judgments for words of clothing does not activate somatosensory cortex, only regions associated with body parts (Goldberg et al., 2006b). However, in this last study, the stimuli were not listed in the paper so it is not clear on what dimensions the clothing words were distinguished. They were said to share "functional" attributes, so similarity could have been judged on how the clothing is used (e.g., on what part of the body it is worn). As such, the texture of clothing was unlikely to be salient for the task. This suggests that texture representations are not automatically activated for words referring to objects experienced through texture, and instead their activation may be more context-specific (see van Dam, van Dijk, Bekkering, & Rueschemeyer, 2012).

Overall then, the majority of studies assessing mental simulation of tactile experience leave open the possibility that activations were caused by explicit processes such as mental imagery, and therefore do not provide evidence for the automaticity of linguistic grounding. There is some evidence that tactile activation can vary in terms of specificity (Brunyé et al., 2012), but most studies so far have grouped tactile-related language together without probing the granularity of the representations.

4.2. Temperature

Temperature features in numerous aspects of daily life, such as food, health and comfort. The conceptualization of temperature is said to involve a "complex interplay between external reality, bodily experience and evaluation" (Koptjevskaja-Tamm, 2015, p. 2). How we communicate about temperature however has been fairly understudied, until the compendium of Koptjevskaja-Tamm (2015) which provides detailed description of temperature in almost 30 languages. From this we learn that languages differ in the number of terms they possess and how they categorize temperature, reflecting in part environmental contingencies of local temperatures experienced across the globe, and in part cultural practices associated with eating and medicine (Koptjevskaja-Tamm, 2015). At the broadest level some generalizations do seem to emerge: if a language has a two-term contrast for temperature it is likely to be cold vs. warm, but if it has a four-term system then it will be cold~cool~warm~hot (Koptjevskaja-Tamm, 2015). This suggests that mental simulation for temperature would at least distinguish between cold and warm. Intriguingly, cold and warm sensations are mediated by different afferent fibres, and in thermoception research they are considered distinct submodalities (Borhani, Làdavas, Fotopoulou, & Haggard, 2017).

Despite the wealth of linguistic variation to be found in this domain, no study has assessed the mental simulation of heat during language comprehension. There are, on the other hand, studies that have examined the behavioural impact of metaphors involving temperature (e.g., *cold shoulder*, *warm character*, see Lee, 2016). Heat and valence are associated at a conceptual and perceptual level (e.g., warm is positive, cold is negative; Bergman, Ho, Koizumi, Tajadura-Jiménez, & Kitagawa, 2015), and there have been studies suggesting such metaphors can impact social experiences (IJzerman & Semin, 2009; Williams & Bargh, 2008). For example, people rate themselves as more similar to another person (greater social proximity) when holding a warm beverage compared to a cold beverage (IJzerman & Semin, 2009), and report feeling more lonely after holding a cold (versus warm or neutral) therapeutic pack (Bargh & Shalev, 2012). However, this research has been treated with some skepticism following failures to replicate (Chabris, Heck, Mandart, Benjamin, & Simons, 2019; Lynott, Corker, Connell, & O'Brien, 2017, 2014; Wortman, Donnellan, & Lucas, 2014), leading researchers to seek alternative paradigms to test the essential premise of a link between physical and social warmth (e.g., Borhani et al., 2017; Fetterman, Wilkowski, & Robinson, 2018). Regardless, such results do not bear directly on the present issue of grounding language of the lower senses, and instead may reflect the association between temperature and social experiences in everyday experience (e.g., the warmth of maternal attachment, the effect of heat on aggression; Lynott et al., 2017) or have a low-level physiological basis (e.g., Borhani et al., 2017).

From a grounded perspective then, to our knowledge, no study has explored the language of temperature. However, behavioural and imaging paradigms discussed in §4.1 related to tactile language could easily be utilized in this arena too.

4.3. Pain

Unlike other aspects of touch, pain is not directly about an external object, but primarily reflects an awareness of one's own body (de Vignemont, 2017), and is entirely subjective (Bonch-Osmolovskaya, Rakhilina, & Reznikova, 2009). Clearly there are complex relationships between pain, temperature, and other aspects of touch (see, e.g., Kammers, Rose, & Haggard, 2011). Nevertheless, pain has a distinct receptor system: some argue it is a separate sense (see Auvray, Myin, & Spence, 2010), or even an emotion (e.g., Craig, 2003).

Language plays a crucial role in our conceptualization of pain, as self-report is the primary way to assess it. Generally, it has been noted that languages have few words specifically for pain (e.g., *hurt*), and that people recruit words from other semantic domains instead (e.g., *my throat feels scratchy*; Bonch-Osmolovskaya et al., 2009; Reznikova, Rakhilina, & Bonch-Osmolovskaya, 2012). Questionnaires have been developed to help patients describe their pain experience, for example the McGill Pain Questionnaire (Melzack, 1975). Melzack (1975) posits three distinct components of pain: sensory qualities (e.g., *pounding*), emotional components (e.g., *terrifying*), and evaluative components (e.g., *annoying*). To characterize the psycholinguistic aspects of pain language, Borelli, Crepaldi, Porro, and Cacciari (2018) created a normed lexicon of pain, including variables such as familiarity, valence, and pain-relatedness. Using hierarchical clustering, ratings of the pain-related words clustered on two dimensions: variables associated with unpleasantness (the affective-motivational dimension) and variables associated with intensity and pain-relatedness (the sensory-discriminative dimension).

As in other semantic domains, claims of ineffability for pain do not take into consideration the crosslinguistic variation that is attested globally (Levinson & Majid, 2014). It is noteworthy in this context that there are several experimental studies of pain in languages other than English—including Danish, German, Chinese, and Japanese—as these languages appear to exhibit distinct resources for talking about pain. Like tactile-related language, the language of pain can be iconic. For example, Japanese contains numerous "mimetic" words for pain. Mimetic words are a distinct grammatical class in Japanese that "evoke a vivid at-the-scene feeling", and native speakers feel there is direct connection between the form of the word and its meaning (Kita, 1997, p. 381). Interestingly, English speakers presented with Japanese pain mimetic words are sensitive to some of the same meaning distinctions as native Japanese speakers (Iwasaki, Vinson, & Vigliocco, 2007). Again, this iconicity may bridge pain experience and pain-related words (Perniss & Vigliocco, 2014).

Pain-related language can affect the experience of pain, suggesting comprehension overlaps with systems involved in pain processing. For example, Danish participants perceived the pain intensity of a noxious stimulus as higher after reading literal pain sentences (e.g., *Anna spilled acid on her hands – it felt burning*) compared to metaphorical pain sentences (*Erik's team lost 0–4 – the defeat was burning*), and the effect was stronger in chronic pain patients than controls (Vukovic, Fardo, & Shtyrov, 2019). However, the automaticity of this effect could be questioned since explicit pain judgments were required. In a different study, Dillmann, Miltner, and Weiss (2000) found that reading words associated with affective pain (e.g., *terrible*) and somatosensory pain (e.g., *burning*), whilst receiving a painful laser-heat stimulus, led to larger laser-evoked brain potentials compared to neutral words. However, Richter et al. (2014) found both pain-related semantic primes and negative affective primes increased pain ratings of noxious electrical stimulation, indicating a general effect of valence rather than a specific effect of pain meaning.

Turning to the brain imaging data, one study with German speakers found that pain-related words (e.g., *excruciating*) activated regions of the brain thought to be relevant to pain both when explicitly imagining pain associated with that word, and when counting the number of vowels in those words in a distractor task (Eck, Richter, Straube, Miltner, & Weiss, 2011). This could be taken as evidence that pain language leads to automatic and specific activation of circuits involved in processing of real pain, but the putative pain-relevant activations were found when comparing pain-related words with a baseline of viewing a

fixation cross. This is potentially problematic as the difference in activation could reflect numerous alternative cognitive processes (e.g., attention). When specifically comparing pain-related words with negatively valenced words, activation of pain systems in the imagination condition was stronger for migraine patients than controls (Eck et al., 2011), and only migraine patients showed activation in the distractor condition, suggesting experience with pain affects simulations of pain, in line with Vukovic et al. (2019). Before accepting this possibility, it is important to point out that although the regions activated in these comparisons are described as being part of the "pain matrix", they have also been associated with processes involved in emotion and decision making (Bechara, Damasio, & Damasio, 2000). Critically, the brain response to real pain is complex and encompasses affective, cognitive, and sensory systems (Peyron, Laurent, & García-Larrea, 2000), which can make it difficult to pinpoint "pain-specific" activations in a satisfactory manner. In sum, it is unclear then whether the activation found by Eck and colleagues reflects simulation of pain, or more general processes such as emotional processing or decision making.

In a different study, Gu and Han (2007) measured brain activity whilst Chinese-speaking participants read words or phrases related to painful actions (e.g., *prick*, *hit by car*) or neutral actions (e.g., *walk*, *watch TV*), and then rated the pain intensity of the described action or counted Chinese characters. Rating pain intensity activated secondary somatosensory regions and the insula which are thought to be involved in the discrimination of pain; but no activation was observed in the anterior cingulate cortex (ACC)—a crucial part of the pain network activated by imagined and hypnotized pain (Derbyshire, Whalley, Stenger, & Oakley, 2004). This could mean that the experience of pain evoked by pain-related language is less vivid or more abstracted than real pain. Note, also, since participants were explicitly asked to rate pain intensity, we cannot conclude whether these activations reflect mental simulation or mental imagery. Furthermore, when asked to do a different task (count the number of Chinese characters), there was no difference between painful and neutral stimuli.

In contrast to Gu and Han, Osaka and colleagues did find activation of the ACC in response to pain language (Osaka, Osaka, Morishita, Kondo, &

Fukuyama, 2004). In this study, Japanese participants were given mimetic words whose sounds are highly imitative of subjective pain (e.g., *zuki-zuki*; a throbbing pain with a pulsing sensation). It is possible that the sound-symbolism of the Japanese words bootstrapped a more vivid simulation of pain (cf. Kita, 1997; Perniss & Vigliocco, 2014; Winter et al., 2017) than the language used by Gu and Han. This points to the importance of knowing the language-specific details of the pain vocabulary being tested in each study. On the other hand, Osaka et al. (2004) did instruct participants to form unpleasant mental images corresponding to the pain-words, which suggests that the activations elicited were due to mental imagery rather than habitual language comprehension per se.

Finally, Richter, Eck, Straube, Miltner, and Weiss (2010) set out to examine whether overlaps in pain language and the experience of real pain is due to the relevance of pain to the stimuli, or instead to overall negative valence or increased arousal. To do this, in addition to pain-related words, German-speaking participants were given negative, positive, and neutral words, and asked to either imagine an associated situation, or complete a distinct distraction task (counting vowels). In both tasks, areas of the brain identified in previous studies as key parts of the pain matrix (including ACC) were activated more to pain-related words than valenced words.

Taken together there is some evidence that pain-related language can activate pain-related systems, and that this activation differs between pain-related language and negatively valenced language. However, it is unclear whether these activations can be attributed to pain, or other processes involving emotion and decision making. The results of Richter et al. (2010) suggest this activation occurs during automatic language processing, but other studies suggest more strategic processing is involved. Differences between studies could rest in details of the specific languages being tested or the particulars of the language materials. As mentioned earlier, the studies of Japanese (e.g., Osaka et al., 2004) have focused on a special class of words—mimetics—which do not exist in Standard Average European languages. It has been claimed that this class of words is particularly evocative of sensory experience (Kita, 1997), and so it might well be predicted that mental simulation of pain would be strongest in response to these. In

contrast, Gu and Han (2007) studied a different class of words altogether—namely verbs and verbal phrases (e.g., *hit by a car*). As well as differing in grammatical class, the studies also differ in the sorts of meanings being investigated. So, while Richter et al. (2010) and Osaka et al. (2004) specifically examined words to describe pain, Gu and Han (2007) investigated action words which merely imply pain as a consequence of the action.

Beyond the relevance for grounded theories of language, the triggering of pain experiences by pain-related language is important for clinical populations. As Dillmann et al. (2000) highlight, chronic pain sufferers are often presented with pain-related language, and pre-activation of pain following this could affect pain thresholds and the overall severity of pain. For example, chronic migraine sufferers experience greater activation of systems involved in pain when imagining pain and reading pain-related words (Eck et al., 2011; see also Knost, Flor, Braun, & Birbaumer, 1997; Vukovic et al., 2019; Weiss, Miltner, & Dillmann, 2003), and depressed individuals show enhanced brain activation and memory for pain words (Nikendei, Dengler, Wiedemann, & Pauli, 2005). Cross-cultural differences in pain-language are also important to consider in clinical situations, where miscommunication—e.g., between doctor and patient—could be harmful (Wierzbicka, 2012).

In sum, only a few studies suggest that the putative "pain matrix" is activated automatically by pain-related language (Eck et al., 2011; Richter et al., 2010); instead activations are likely to be driven by explicitly thinking about pain (Gu & Han, 2007; Osaka et al., 2004). It is not clear what precise aspect of pain is activated—is it the pain quality, intensity, or duration (Rowbotham, Holler, Lloyd, & Wearden, 2012)? Nor is it clear how activations map onto the pain components proposed for language (Borelli et al., 2018; Melzack, 1975).

4.4. Interoception

Another neglected perceptual modality, not traditionally included in discussion of the senses, is interoception (see Tsakiris & De Preester, 2018). More recently it has been proposed that systems involved in interoception should also be recruited for mental simulation, along with perception and action (van Dantzig et al., 2008). Interoception refers to sensations in the body, including experiences such as hunger, heartbeat,

headache, and itch. Such experiences may be more important for abstract word meanings (e.g., *hungry*) than concrete word meanings (e.g., *rainy*; Connell, Lynott, & Banks, 2018; Desai, Reilly, & van Dam, 2018), and therefore present a challenge to claims that grounded approaches to language cannot explain abstract meanings (e.g., Dove, 2009; Mahon & Caramazza, 2008).

Connell et al. (2018) collected modality exclusivity ratings for over 32,000 words and included interoception as one of the perceptual modalities. Interoception ratings were found to be particularly high for negative emotions such as *fear* and *sadness*. Including interoception ratings in a model of word recognition was also found to explain response times over and above the traditional five-sense model, providing evidence that interoception is indeed an important component in the representation of word meaning. A recent study reported that primary interoceptive cortex (dorsal posterior insular) was activated when participants imagined being in a situation that involved vivid internal sensations (Wilson-Mendenhall, Henriques, Barsalou, & Barrett, 2019). In this study participants read paragraphs describing a richly detailed experience and were instructed to imagine "being there". Crucially, this activation was found after controlling for affect. Future studies are required to ascertain whether the same systems are activated when participants merely comprehend interoceptive language, rather than actively engage in imagination.

5. Taste

When we refer to taste in everyday talk, we most often mean "flavour" according to current scientific terminology. In this review, we stick to everyday parlance for ease. As mentioned in the Introduction, taste strongly involves retronasal olfaction—smelling via the oral cavity during eating and drinking (the other type of smelling in addition to via the nose—orthonasal olfaction). This means that most taste-related words are also strongly odour-related (Lynott & Connell, 2009, 2013; Speed & Majid, 2017a; Winter, 2016). Furthermore, flavour encompasses almost all sensory modalities (Auvray & Spence, 2008; Shepherd, 2006), including the visual experience of food and drink consumed; the texture of it in our mouth (mouth-feel); the temperature, etc. The multisensory nature of flavour elucidates why flavour imagery is often rated as

more vivid than odour imagery (Andrade et al., 2014; Croijmans, Speed, Arshamian, & Majid, 2019). One might predict, therefore, that flavour-related language is also easier to mentally simulate.

Some suggestive evidence for the importance of taste simulation in the representation of food language comes from a study by Papies (2013). In this experiment, Papies used a feature-listing task to examine the types of representations that underlie the meaning of food words. Participants were given labels for four attractive but unhealthy foods (*vanilla ice cream, cookies, cocktail nuts, chips*) and four neutral, but healthy foods (*cucumber, apple, banana, rice*) for which they had to generate properties. Overall, food words were given features thought to reflect eating simulations: including basic tastes (e.g., *sour*), texture (e.g., *soft*), and temperature (e.g., *warm*); eating situations (e.g., *good for dinner*); and hedonic features (e.g., *tasty*). Words for food that was more tempting (attractive, but unhealthy) led to more taste, texture, and temperature features; whereas neutral food words were primarily given features related to vision (e.g., *red*). This suggests tempting food words are represented more in terms of actually eating the food than neutral food words.

A feature-listing task however is not the strongest test of grounding, since there are numerous other routes for how the features could be generated (e.g., word associations, amodal features; cf. Louwerse & Connell, 2011). Although Papies (2013) does not provide direct evidence that sensorimotor experience forms the meaning of food words, the study is pioneering because it suggests that sensory experience related to the taste and mouthfeel of food is important—and more so for food that is more enjoyable. To our knowledge only one other study has explored mental simulation of taste using behavioural methods. Using the modality-switch paradigm described earlier (cf. van Dantzig et al., 2008), Pecher, Zeelenberg, and Barsalou (2003) found property judgments on concept-property pairs (e.g., *LEMON-sour*) were faster following a concept-property pair in the same modality (e.g., *CRANBERRIES-tart*) than concept-property pairs from a different modality (e.g., *BLENDER-loud*). However, in this study, responses were collapsed across modalities (audition, vision, taste, smell, touch, and motor), so we do not know to what extent the "modality-switch" effect was observed for taste-related judgments in particular (see §4.1).

Perceptual detection tasks have shown that the primary taste cortex (the insula and frontal operculum) can be activated in the absence of a taste stimulus (Veldhuizen, Bender, Constable, & Small, 2007), so in principle it might be possible for language to do so too. Taste and flavour perception can be influenced by language, and it is possible that a grounded account of taste language can explain this. The taste of umami, and flavour of umami-plus-vegetable-odour is processed differently depending on whether it is described as "rich and delicious" or more literally as "monosodium glutamate" or "boiled vegetable water" (Grabenhorst, Rolls, & Bilderbeck, 2008; see also Yeomans, Chambers, Blumenthal, & Blake, 2008). This difference is observed in early cortical areas that process the affective value of taste and flavour (but not primary taste cortex), but also affective responses to stimuli in other modalities. Thus, taste-related language (or language describing the hedonic aspect of taste) may be grounded in what are referred to as "secondary" taste areas of the brain, although there is no evidence that these activations are modality-specific.

As with touch, researchers have investigated whether metaphors involving taste affect behaviour—even without explicit presentation of the metaphor. For example, in line with the metaphor "variety is the spice of life", eating spicy food apparently leads people to demonstrate greater variety in their choices and more risk-taking (Mukherjee, Kramer, & Kulow, 2017; Wang, Geng, Qin, & Yao, 2016). Thinking about a romantic experience can affect perceived sweetness of tastants (Chan, Tong, Tan, & Koh, 2013), and conversely a sweet taste can lead to more favourable judgments of a relationship (Ren, Tan, Arriaga, & Chan, 2015). There also appears to be a link between a preference for sweet tastes and prosocial behaviour (cf. *she's a sweetie*; Meier, Moeller, Riemer-Peltz, & Robinson, 2012). Intriguingly, such metaphors differ cross-culturally. In Hebrew, *spiciness* is used as a metaphor for "intellectual competence", while *sweetness* is used for "inauthenticity". In line with these metaphors, Gilead, Gal, Polak, and Cholow (2015) found that spicy tastes led to high social evaluations, whereas sweet tastes increased judgments of inauthenticity. Similarly, *bitter* in English can be used for situations involving unfairness, but *eating bitterness* in Chinese refers to endurance in the face of hardship. Xu (2017) found that giving Chinese, but not English speakers, bitter

tastes increased their judgements of effort and motivation under a scenario with adverse circumstances. However, there are numerous factors that could be responsible for such behavioural effects (e.g., valence, motivation), so these studies cannot be considered as evidence for automatic activation of taste; and as with the temperature literature reviewed earlier (§4.2), there are questions surrounding the robustness of some of these findings (e.g., Ashton, Pilkington, & Lee, 2014) thereby warranting further investigation.

Brain imaging studies suggest that taste representations are activated for taste-related words, but on closer inspection the findings are not unequivocal. In Spanish participants, Barros-Loscertales et al. (2012) found that passively reading taste-related words (concrete nouns, e.g., *cebolla* "onion") activated primary (insula and frontal operculum) gustatory cortices more than words with little or no taste associations (e.g., *blusa* "blouse"). Secondary regions were also activated (OFC), but since activation of the OFC is thought to reflect processing of the affective value of taste— since it can also be activated by tasks related to other sensory modalities (e.g., see Bechara et al., 2000)—it can also be interpreted as reward processing generally, not taste-specific reward.

Although the authors claim their findings show semantic activation in gustatory regions without the need of an explicit semantic task—and thereby constitute evidence for an automatic effect—a critical examination of the paradigm used in this study makes clear that the task involved silently reading taste-related words with a gap of 2 s between each word. During passive reading participants could be deliberately imagining the word referent which then leads to activation of the gustatory system (Kikuchi, Kubota, Nisijima, Washiya, & Kato, 2005; Kobayashi, Sasabe, Shigihara, Tanaka, & Watanabe, 2011; Si & Jiang, 2017). This may be particularly likely since taste words were presented in a block together, making taste a salient attribute. Results from this paradigm cannot, therefore, definitively reveal whether these activations are critical and automatically activated in semantic processing.

In addition, the words used in this experiment differed on semantic ratings of vision and olfaction, so the findings cannot be attributed solely to taste. Along these lines, premotor brain regions were also activated more for taste-related words, although this probably reflects the act of eating itself rather than the taste sensation. A different study showed both primary and secondary gustatory cortex activation by metaphorical expressions involving taste (e.g., *She looked at him sweetly*; Citron & Goldberg, 2014). However, this fMRI paradigm still affords the possibility of taste imagery; although perhaps less likely since the primary meaning of the sentence is not related to taste.

In contrast to Barros-Loscertales et al. (2012) and Citron and Goldberg (2014), Goldberg and colleagues (Goldberg et al., 2006b; Goldberg, Perfetti, & Schneider, 2006a) found words with taste-related properties activated only putative secondary gustatory regions (left orbitofrontal cortex); not primary gustatory regions (the same has been observed with pictures of appetizing food; Simmons, Martin, & Barsalou, 2005). The authors concluded that the regions activated were responsible for semantic knowledge of flavour, flavour identity, and the reward value of taste (Rolls, 2004), but as highlighted earlier, this "secondary" activation is not necessarily modality-specific. Both studies involved fairly explicit tasks (property verification judgments and generating items related to a target and then judging similarity), but in comparison to Barros-Loscertales et al. (2012) provided less opportunity for strategic imagination of the word referents.

To definitively establish the extent of simulation in taste language, a more systematic research programme is required. It is known that specific task features determine gustatory activation: for example, imagined tastes affect real taste perception when people engage in deliberate imagery, but not when the same task is performed in a more analytical manner (Si & Jiang, 2017). Given such findings, future studies could explicitly manipulate task requirements in order to test which processes lead to activation of gustatory cortices, with the view to establishing the limits and possibilities of grounding for this perceptual modality.

Overall, there is little evidence that low-level gustatory systems are activated automatically during language comprehension—the findings of Barros-Loscertales et al. (2012) could be explained by gustatory imagery. Other studies have found activations in regions that process aspects of taste, such as valence, using explicit tasks (Goldberg et al., 2006a, 2006b; but see Citron & Goldberg, 2014), although this activation may not be taste-specific. No research

has set out to test the specificity of taste simulation, although the work of Papies (2013) suggests tempting and healthy foods may be represented differently. Given the dearth of studies even attempting to assess the grounding of taste language, there is ample room for future studies to contribute novel insights in this arena. Such contributions would be particularly welcome, given the critical importance of food, and the various related challenges facing humanity today—obesity, malnutrition, sustainability—so as to harness language to effect change.

6. Olfaction

As mentioned in the introduction, it has been said that odour and language are weakly connected in the brain. Since odours are apparently difficult to name, researchers have suggested this is because of a neural-architectural limitation: some suggest olfactory and language areas of the brain have inherently weak links (e.g., Engen, 1987), others posit the neural codes interfere with one another (Lorig, 1999), or more recently that olfactory and language areas are too directly connected (Olofsson & Gottfried, 2015). According to Olofsson and Gottfried (2015), the piriform cortex (the primary olfactory cortex) is too immediately connected to language regions of the brain, which means that olfactory representations remain coarse and unprocessed at the point of lexical-semantic integration. Despite this suggestion, some studies propose that language can activate olfactory representations.

Evidence from behavioural studies not directly designed to test grounded theories nevertheless suggest odour-related words activate odour representations; although these studies are open to other interpretations. For example, Olofsson, Bowman, Khatibi, and Gottfried (2012) found that responses to odours were facilitated when they were preceded by a matching (e.g., *lemon* and lemon odour) compared to mismatching odour label (e.g., *almond* and lemon odour). The authors concluded that this facilitation was evidence that odour labels activate "odor object templates". However, it is not clear whether such templates consist of low-level olfactory representations, or have some other format instead. Facilitation could also occur if participants silently labelled the odour upon its presentation (i.e., a label-match facilitation). Alternatively, both the word and the odour may have

activated another common perceptual representation that led to facilitation (such as colour; see §7.2 on crossmodal compensation).

Other preliminary evidence for the possible grounding of odour comes from a study where participants had to make a semantic judgment ("is this an animal or not?") about odour-related words (e.g., *strawberries*) and neutral words (e.g., *buttons*) in the presence or absence of an ambient pine odour. Responses were delayed for odour-related compared to neutral words when the odour was present (Boddy, Paz-Alonso, & Yee, 2016). Since olfactory representations were irrelevant for the task, this interference suggests olfaction might nevertheless be automatically activated when comprehending olfactory language, although we cannot ascertain at what level of specificity. It is also not clear whether an awareness of the ambient odour contributed to the effect observed in this initial data. This also applies to other studies where an ambient odour was used to explore the effects of the olfactory metaphor "something smells fishy" on behaviour (Lee, Kim, & Schwarz, 2015; Lee & Schwarz, 2012). The smell of fish was found to induce feelings of suspicion, and vice versa, feelings of suspicion affected detection of a fishy odour (Lee & Schwarz, 2012). It is incumbent upon future research to rule out possible demand characteristic explanations for such effects.

Further behavioural evidence fails to provide conclusive evidence for mental simulation of odour. As described earlier, in a study of the modality-switch effect, where responses to same modality trials were faster than responses to switched modality trials, responses were collapsed across modalities, making it unclear whether the effect would be observed for odour-language specifically (Pecher et al., 2003, §5). Other studies have shown that the perceived pleasantness of odours can be affected by how they are described (de Araujo, Rolls, Velazco, Margot, & Cayeux, 2005; Herz, 2003; Herz & Clef, 2001), and this is also discernible through activation of parts of the brain that process the hedonic value of odours (de Araujo et al., 2005). However, activation was stronger in the presence of an odour compared to clean air (de Araujo et al., 2005), suggesting language may have difficulty affecting odour activations if they are not already active.

Using a similar fMRI paradigm as Barros-Loscertales et al. (2012) who studied taste-related words, González

et al. (2006) found that when Spanish participants read odour-related words (e.g., *canela* "cinnamon") the piriform cortex (the primary olfactory cortex) was activated. This result is unexpected given the proposal that language poorly connects with olfaction. This study faces the same shortcoming observed in Barros-Loscertales et al. (2012), namely a 3 s gap occurred between presentation of each word. In this time frame, participants have time to actively think about the referent of the word, so any activation might not reflect online language comprehension and mental simulation alone, but deliberative thoughts and imagery of odour. This is in line with evidence showing that olfactory mental imagery (Bensafi et al., 2003; Bensafi, Sobel, & Khan, 2007), active odour search (Zelano, Mohanty, & Gottfried, 2011), and explicit recall of odour-evoked autobiographical memory from words (Arshamian et al., 2013) activates the piriform cortex. So, this is all good evidence that low-level olfactory representations can be deliberately activated in the absence of odour stimuli, but not necessarily automatically during language comprehension. Finally, another possible explanation for piriform cortex activation in the González et al. study is that while thinking about the meaning of words, participants engaged in greater sniffing behaviour which happens during odour imagery (Bensafi, Pouliot, & Sobel, 2005) and leads to piriform activation (Mainland & Sobel, 2006; Sobel et al., 1998).

One possible account of the apparent inconsistency between the finding that odour language is grounded in olfaction (González et al., 2006), on the one hand, and the putative difficulty of odour naming, on the other, is that odour-related words and olfactory representations are connected in a broad manner. So rather than a word like *cinnamon* activating specific olfactory representations related to the odour of cinnamon, it instead activates a schematic, or coarse-grain, olfactory representation (cf. Barsalou, 2003). In order to test this idea, Speed and Majid (2018a) conducted a behavioural experiment assessing whether odour-related words affect memory for real odours. Participants held an odour-related word in mind (e.g., *cinnamon*) whilst they smelled an odour and made judgments about it. Subsequently memory for the odours was tested with a recognition test. To assess whether odour-words activate fine-grained or broad olfactory representations, the relationship between each word and odour was manipulated:

words either matched the odour (e.g., *cinnamon* and cinnamon odour), were a near-match (e.g., *nutmeg* and cinnamon odour), were a mismatch but still odour-related (e.g., *garlic* and cinnamon odour), or were not related to olfaction (e.g., *glitter*). The same experiment was conducted with sound-related words and real sounds as a comparison modality. None of the odour-related words affected memory for odours; in contrast, sound-related words that were a match or a near-match to real sounds (e.g., *bee* or *buzzer* with bee sound) interfered with memory for sounds. This suggests olfactory language is not grounded in primary perceptual representations, even at a coarse-grain, whereas auditory language is (e.g., Kaschak et al., 2006; Kiefer et al., 2008).

In addition to measuring recognition memory, Speed and Majid (2018a) also measured explicit judgments of intensity, pleasantness, and familiarity for the odours. While the odour-word relationship (i.e., match, near-match, mismatch, neutral) did not affect memory, it did affect these higher-level judgments. Specifically, odours were rated as more intense and pleasant when they had been paired with a match or near-match word (e.g., cinnamon odour with *cinnamon* or *nutmeg*). These judgment effects were not apparent in the auditory equivalent of this experiment. Taken together, this suggests that odour perception and odour-related language may interact at high levels of processing (e.g., where odour valence is explicitly judged), but they do not at low-level perception (i.e., where odour quality is represented). Alternatively, since odours are thought to be processed primarily in terms of valence (e.g., Yeshurun & Sobel, 2010), it could mean instead that the meaning of odour-language is grounded in emotion (see §7.2).

A subsequent brain imaging study supports Speed and Majid's (2018a) conclusion that olfactory language activates representations of odour valence, but not low-level perceptual representations. Pomp et al. (2018) conducted an experiment in German where participants read sentences that were either olfactory metaphors (e.g., *Er kann ihn absolut nicht riechen*; "He cannot smell him at all" meaning "He cannot stand him"), literal paraphrases (e.g., *Er kann ihn absolut nicht ausstehen*; "He cannot stand him at all"), or literal olfactory sentences (e.g., *Er riecht sehr unangenehm*; "He smells very unpleasantly"). Both literal and

metaphorical olfactory sentences activated secondary olfactory regions of the brain (the orbitofrontal cortex; OFC), possibly reflecting odour valence (Rolls, 2004), but neither activated the piriform cortex. Recall that this region of the brain is also involved in pain (Eck et al., 2011) and taste processing (Barros-Loscertales et al., 2012), so it cannot be defined as modality-specific. The lack of effect is surprising given the findings of González et al. (2006), where piriform activation was observed for odour-related words, and particularly so given the evidence that mental simulations are represented more strongly for sentences than single words (Bergen, Lindsay, Matlock, & Narayanan, 2007).

On the other hand, one could argue the discrepancy lies in the fact that the sentence stimuli of Pomp et al. (2018) do not refer to specific odours but general odour experiences (e.g., "He smells very unpleasantly"); but this would apply to only 8 out of 35 sentences. The remaining 27 sentences explicitly refer to an odour source (e.g.,"garlic" in *Es ist schlecht für die Karriere, wenn man immer nach Knoblauch riecht;* "It's bad for a career, always smelling of garlic."). Pomp et al. (2018) suggest the lack of piriform activation is due to the overall hedonicity of the olfactory sentences—which highlight a pleasant or unpleasant odour experience—and therefore activate secondary olfactory regions where odour valence is processed. However, since valence is thought to be the primary dimension by which odours are encoded (Khan et al., 2007; Majid et al., 2018; Yeshurun & Sobel, 2010; Zarzo, 2008; although see Olofsson et al., 2012; Olofsson, Bowman, & Gottfried, 2013), and odour language is also strongly encoded along this dimension (Levinson & Majid, 2014; Winter, 2016; Wnuk & Majid, 2014) piriform activation ought to be expected on a fully grounded perspective.

A recent study examined German odour-related words in individuals with olfactory loss, as well as controls, and also found no activation of primary olfactory areas—even though participants were instructed to prepare for the presentation of "words with smell" (i.e., attention was directed to the olfactory dimension; Han et al., 2019). In addition, although activation of language-related brain areas differed between groups during word expectation, no differences were observed during odour-word presentation. This suggests deficits in olfactory processing may not affect odour language comprehension, in direct contrast with evidence from people with action deficits who display differential processing of action language (e.g., Bak, O'Donovan, Xuereb, Boniface, & Hodges, 2001; Fernandino et al., 2013). This is further evidence that González et al. (2006) have captured something other than mental simulation in their study.

One final piece of evidence that low-level olfactory representations do not play a role in the comprehension of odour-related language comes from a patient study. According to grounded accounts of meaning, perceptual difficulties with olfaction should also lead to difficulties with words related to olfaction. To the contrary Luzzi et al. (2007) found that although patients with Alzheimer's disease (AD) were impaired in odour discrimination and odour-picture matching compared to control participants, they were unimpaired for picture naming and word-picture matching for the same concepts. Their perceptual deficit did not lead to a conceptual deficit. It should be noted, however, that only accuracy of picture naming and word-picture matching was measured—not response time—where conceptual deficits in patients have been observed previously (e.g., Fernandino et al., 2013; Speed, van Dam, Hirath, Vigliocco, & Desai, 2017). More critically, picture naming and word-picture matching can easily be completed by relying on visual representations alone—i.e., without the necessity of activating conceptual representations related to odour—so it is not clear there was a sound basis to predict a difference between the two groups in the design above. Furthermore, when a patient is impaired in one perceptual modality it is not necessarily the case that they are entirely impaired in a related conceptual task, so long as a partially redundant modality can be utilized to perform the task instead (Barsalou, 2016).

On the whole, then, there is no convincing evidence to date that odour-related language activates low-levels of olfactory processing in the absence of deliberative odour imaging, supporting the idea that odour and language are weakly connected in the brain for comprehension, as well as production, as has long been claimed (Engen, 1987; Lorig, 1999; Olofsson & Gottfried, 2015)—at least for the languages studied to date. Instead odour-related language may activate regions that process valence (Pomp et al., 2018; Speed & Majid, 2018a) at the level of broad odour categories (i.e., odours that are similar such as *cinnamon* and *nutmeg*; Speed & Majid, 2018a).

7. Discussion

7.1. Assessing the evidence

The results reviewed here suggest that mental simulation related to the lower senses may be difficult, and less common than for the "higher" senses of vision and audition (e.g., Luzzi et al., 2007; Pecher et al., 2003; Speed & Majid, 2018a; van Dantzig et al., 2008). The evidence for overlap in brain activation for sensory language and perception is tenuous at best (e.g., Goldberg et al., 2006a, 2006b; Pomp et al., 2018), with most studies unable to rule out the engagement of strategic mental imagery in their tasks. While there is stronger evidence for the activation of secondary sensory regions for taste and smell language, such activation suggests a different level of specificity than activation of primary olfactory and gustatory regions. In fact, since activations in these regions appear to overlap for odours, tastes, and pain, as well as other types of stimuli (Bechara et al., 2000), it is unclear to what extent they can be defined in terms of a particular modality. Chatterjee (2010) proposed that representations are progressively "bleached" of sensorimotor content as they are processed further from primary regions. Activation of secondary gustatory and olfactory cortices (coding for features such as valence) rather than primary regions (coding for taste and odour quality) appears to be depart from what is often seen for vision- and audition-related language, where activation tends to be "just anterior to" primary regions instead. This suggests mental simulation of smell and taste includes abstracted, schematic representations (cf. Speed & Majid, 2018a), at least in speakers of English and other Standard Average European languages where these ideas have been tested. Given the scarcity of research in this area, this conclusion certainly requires further support before it can definitively be accepted.

In addition, we do not yet know what the consequence is of a simulation that is more or less abstracted. The phenomenology of language processing could differ—for example, a story could be less vivid when experienced as a more abstracted simulation. Memory of linguistic stimuli could also be affected: low-level simulations could facilitate recall of detail, whereas high-level simulations could facilitate recall of gist. This might be important in the domain of health and marketing, where language is used to persuade people to choose certain products

(e.g., Hanks, Just, & Brumberg, 2016; Turnwald, Boles, & Crum, 2017). On the other hand, perhaps specificity does not matter. If language can only activate representations of odour and taste valence, this may nevertheless be sufficient to affect behaviour. Only further research disentangling these issues can shed light on the matter.

At present, little research has assessed the automaticity of activations of the lower sensory systems. Many studies leave open the possibility for strategic mental imagery (Barros-Loscertales et al., 2012; González et al., 2006; Osaka et al., 2004) or involve explicit judgments about the modality of interest (Brunyé et al., 2012; Connell & Lynott, 2010; Derbyshire et al., 2004; Osaka et al., 2004). The evidence for the automatic mental simulation of touch is perhaps stronger, with texture regions of the brain activated when reading and understanding texture-related sentences (Lacey et al., 2012). In order to critically assess the automaticity of mental simulations, future studies could focus on the time-course of activations (e.g., Ostarek & Vigliocco, 2017), or use tasks less likely to elicit strategic mental imagery and more akin to everyday language use, such as narrative comprehension (Kurby & Zacks, 2013; Willems & van Gerven, 2018).

7.2. Crossmodal compensation

If low-level perceptual representations in the lower senses are not mentally simulated during language comprehension, or simulated only at a schematic level, perhaps language related to these senses is not comprehended at sufficient depth, leaving shallow, "good enough" representations (Ferreira, Engelhardt, & Jones, 2009). We suggest that in such situations "crossmodal compensation" is an option. We do not experience objects and events in the world through only one modality, but multiple; therefore conceptual representations also require access to multimodal features (van Ackeren & Rueschemeyer, 2014; van Ackeren, Schneider, Musch, & Rueschemeyer, 2014). We propose that associated modalities (which may better afford mental simulation) may scaffold meaning when mental simulation in a particular modality is difficult. This form of mental simulation is different to metaphorical extension, where one modality is used to explain a typically unrelated modality (e.g., Lacey et al., 2012). Instead, crossmodal compensation involves the recruitment of modalities

or experiences highly associated with the referential object or event, or representations in partially redundant perceptual modalities, to compensate for reduced simulation in the lower senses (Barsalou, 2016).

For odour-related language, which appears to be absent of odour simulation (Han et al., 2019; Pomp et al., 2018; Speed & Majid, 2018a), representations of word meaning may rely more strongly on simulation in vision to help scaffold meaning. Support for this idea comes from modality ratings, where vision is the second strongest associated modality with odour-dominant words (Speed & Majid, 2017a). One specific visual dimension that could be crossmodally simulated for odour-related language is colour. Colour may form a critical component of the meaning of odour-related words like *coffee* or *mint* because colour is integral to the real-world experience of the referents, although odour may be more relevant in real-world experience itself. It has been shown that odours and colours are crossmodally associated (e.g., de Valk, Wnuk, Huisman, & Majid, 2017; Speed & Majid, 2018b). Crucially, these odour-colour associations play a role in odour language, suggesting colour is a crucial component of the semantic representation of odour words (Speed & Majid, 2018b). Individuals with odour-colour synaesthesia, who have automatic colour associations when they smell odours, were found to be better at naming odours than matched controls. Even in individuals without synaesthesia, consistency of odour-colour associations predicted accuracy of odour naming. Speed and Majid (2018b) suggest that strong associations between odour and colour may strengthen associated odour-related concepts. It is likely that existing fMRI studies of odour language (i.e., González et al., 2006; Pomp et al., 2018) were not designed in such a way to allow detection of activation in colour regions. However, González et al. (2006) did observe activation within the middle occipital gyrus/lingual gyrus, thought to be involved in visual processing (e.g., Macaluso, Frith, & Driver, 2000).

Temperature may also be associated with odour, as odours can lead to temperature perception via the trigeminal system (e.g., the coolness of mint). There may also be cultural beliefs that lead to odour-temperature associations, such as the use of temperature in medicine (Wnuk, de Valk, Huisman, & Majid, 2017). Similar grounding is also likely for taste-related language, as

taste and flavour are also strongly associated with colour (see Spence, Levitan, Shankar, & Zampini, 2010), and temperature (Ho, Van Doorn, Kawabe, Watanabe, & Spence, 2014). Although people can make consistent associations between texture and colour (Ludwig & Simner, 2013), colour is not found to affect texture judgments of food (Christensen, 1983).

Spatial representations relevant for specific concepts may also be simulated. For example, we can experience the taste of wine in our mouth and the texture of sand on our skin. The relevance of space has been investigated for concepts that are typically experienced high or low in space. Studies show that speed of responses to words are affected by whether they are presented in a spatially congruent (e.g., *hat* in high position) or incongruent (e.g., *hat* in low position) positions (e.g., Estes, Verges, & Barsalou, 2008; Ostarek & Vigliocco, 2017). Instead of vertical space, Speed and Majid (2017a) examined mental simulation of proximal and distal space. Touch and the chemical senses are considered "proximal" senses, and vision and audition "distal senses" (Cytowic, 1995; Howes, 2003; Majid & Levinson, 2011; San Roque et al., 2015). To assess whether near-far space is mentally simulated, Speed and Majid (2017a) used a lexical decision task with words presented either near (proximal space) or far (distal space) on a screen. Responses to words strongly related to olfaction (e.g., *eucalyptus*) were facilitated in proximal space compared to words dominant in other modalities. This implies olfactory-related concepts are mentally simulated close to the body, possibly reflecting the act of sniffing or inhaling odours (Speed & Majid, 2017a).

Although not a "modality" per se, another way that language can be grounded is via emotional simulation (e.g., Kousta, Vigliocco, Vinson, Andrews, & Del Campo, 2011; Vigliocco et al., 2014; Vigliocco, Meteyard, Andrews, & Kousta, 2009). Vigliocco and colleagues propose that emotional content plays a crucial role in the representation of abstract concepts (in addition to linguistic associations), whereas concrete concepts are instead predominantly grounded in sensorimotor simulation. This proposal could also be translated to the current domains if one assumes that the language of the lower senses is more abstract than language related to vision and audition. But note that Majid et al. (2018) find no difference in emotional grounding

of odours (in terms of facial expression) in speakers of a language with concrete odour descriptors (Dutch) and speakers of a language with abstract odour descriptors (Jahai).

Existing evidence supports a role for emotional simulation for taste and smell language in particular. Olfaction and gustation are strongly tied to emotion in the brain (Rolls, 2004; Royet, Plailly, Delon-Martin, Kareken, & Segebarth, 2003), and valence is thought to be the primary dimension on which odours and flavour are perceived (Khan et al., 2007; Sakamoto & Watanabe, 2016; Yeshurun & Sobel, 2010; Zarzo, 2008). Moreover, taste- and smell-related language often occurs in valenced contexts, such as the phrases *fragrant kiss* or *sweet delight* (Winter, 2016). Like abstract words then (Kousta et al., 2011), valence may also be a crucial part of the semantic representation of taste and smell (Majid et al., 2018). This is supported by activation of the amygdala for taste- and smell-related words (Barros-Loscertales et al., 2012; González et al., 2006); although the taste words and control words in Barros-Loscertales et al. (2012) were matched on valence, suggesting another explanation for the difference may be required. Similarly, in ratings of emotion, Speed and Majid (2017a) found no difference across visual, auditory, haptic, gustatory, and olfactory dominant words in ratings of valence, arousal, and dominance. However, it is plausible that emotion ratings in this context reflect the overall valence of the multimodal object, rather than specific taste or smell aspects— compare the valence of *garlic* the word, to the valence of the smell and taste of garlic in a freshly baked piece of garlic bread. We also know that it is difficult to imagine odours (Arshamian & Larsson, 2014), and therefore it may be difficult to accurately judge the valence of an odour in its absence. From another perspective, emotion is thought to be a fundamental dimension of taste and smell (i.e., integral to the perceptual experience itself; see Yeshurun & Sobel, 2010), so emotional simulation could perhaps be considered within-modality simulation. The same argument can be made for pain, where some argue pain just is an emotion (Craig, 2003).

To summarize, there are numerous ways in which language of the lower senses could be crossmodally grounded to compensate for reduced simulation — via colour, space, emotion, and more. One way in which to test this proposal is to compare activation of the perceptual systems during real-world perception and during language comprehension. If crossmodal compensation occurs, then activation within the supporting modality should be relatively stronger during language comprehension than in real-world perception.

7.3. Future directions

It is possible that the sparsity of research on the lower senses reflects the difficulty of investigating mental simulation within these senses. As described in the Introduction, the senses of touch, taste, and smell are less well understood than vision and audition. Furthermore, studies within these modalities often require more elaborate equipment than a computer and headset. Over time, with greater understanding of these senses, we may see evidence of simulation within the lower senses emerging. But, at this moment, the data suggest the grounding of language is not the same across the senses.

It is crucial for the advancement of this field that future studies aim to conduct more stringent tests of the automaticity of the activation of the lower senses—for example, by reducing the potential for mental imagery. In addition, there are a number of other directions for further research within this domain. Below we describe how manipulations of context, differences in experience—such as expertise— and cross-cultural differences are critical arenas to investigate the grounding of the lower senses.

7.3.1. Context

Numerous researchers have highlighted the important role of context in mental simulation (e.g., Lebois et al., 2015; van Dam et al., 2012; Zwaan, 2014), and this is likely to be highly relevant in the grounding of touch, taste, and smell. One important contextual factor is depth of language processing. It has been shown that mental simulations are involved in deep levels of language processing—where meaning is retrieved—but not during shallow levels, where only surface-level meaning, or statistical linguistic information, is accessed (Louwerse & Jeuniaux, 2010). Mental simulations may also only be present when the task makes particular features salient and available (Kemmerer, 2015; Lebois et al., 2015; van Ackeren, Casasanto, Bekkering, Hagoort, & Rueschemeyer, 2012; van Dam et al., 2012). Along these lines, de

Araujo et al. (2005) found that language activated the olfactory cortex to a greater extent when processing an actual odorant than when responding to clean air. Further work is needed to explore whether stronger evidence for mental simulation of the lower senses can be acquired for tasks encouraging deep levels of processing. One possibility still to be explored is whether contexts that highlight perceptually relevant features elicit increased simulation of the lower senses, including fine-grained perceptual distinctions. For example, reading words like *cinnamon* and *nutmeg* may elicit activation of primary olfactory cortices if they are portrayed as dish ingredients on a menu.

7.3.2. Experience

Mental simulation of the lower senses may also be affected by personal experience. This has been observed for action language, in line with the body-specificity hypothesis (Casasanto, 2009): handedness (i.e., right vs. left handed) affects activation of the premotor cortex of the associated hemisphere in response to action words (Willems, Hagoort, & Casasanto, 2010); and experienced ice-hockey players show greater activation of the premotor cortex to sentences about ice-hockey actions than novices (Beilock, Lyons, Mattarella-Micke, Nusbaum, & Small, 2008; Lyons et al., 2010). There is also a suggestion that these effects extend to perception too. Musicians activate parts of the auditory cortex when viewing images of musical instruments, but laypersons do not (Hoenig et al., 2011). In addition, there is evidence that personal experience with events and actions affects the functional connectivity between visual and motor systems when listening to sentences describing those experiences (Chow et al., 2015). This opens up the possibility that greater experience with the lower senses leads to stronger activation of the relevant perceptual systems during language comprehension.

One way in which to address the effect of experience on language processing is expertise. There are numerous types of odour and taste experts, such as sommeliers, perfumers, and chefs. Indeed, evidence suggests olfactory expertise can affect olfactory language (Croijmans & Majid, 2015; Sezille, Fournel, Rouby, Rinck, & Bensafi, 2014), olfactory imagery (Delon-Martin, Plailly, Fonlupt, Veyrac, & Royet, 2013), and organization of the olfactory cortex (Delon-Martin et al., 2013; Plailly, Delon-Martin, & Royet,

2012). Taking this evidence together, it appears odour experts may also have stronger mental simulation of olfaction, but this has yet to be empirically demonstrated.

Other types of personal experience may also be relevant, as has been shown for pain. Reuter, Werning, Kuchinke, and Cosentino (2017) found that people who are more sensitive to pain are likely to rate pain-related words (e.g., *syringe*) as more associated with pain than people less sensitive to pain. Similar findings exist in clinical populations. Eck et al. (2011) found that chronic migraine sufferers experienced greater activation of pain systems to pain-related language than controls (compared to non-pain-related negative adjectives; see also Ritter et al., 2016). In addition to greater activation of anterior insula and OFC (related to affective experience of pain), migraine sufferers showed greater activation of medial temporal lobe structures, which the authors take to reflect more detailed and vivid mental scenes imagined by the patients than controls (Eck et al., 2011).

7.3.3. Cross-cultural differences

As discussed at the beginning of this review, the language of the lower senses may be limited in terms of the lexicon—in English and allied languages. There are few words to describe our experiences related to touch, taste, and smell, in comparison to vision and audition (Levinson & Majid, 2014; San Roque et al., 2015; Winter et al., 2018). One argument for the lack of evidence of automatic, specific mental simulation in the lower senses then could be that Western languages are missing the right words. However, there is increasing evidence that perceptual language may differ across cultures in profound ways (Majid et al., 2018) which opens up the possibility to test the grounding of the lower senses in communities with a qualitatively different vocabulary.

Olfaction is one domain where the contrast between Western languages and lesser-studied languages is particularly salient. Not only do hunter-gatherer communities show higher codability for smell than non-hunter-gatherer communities (Majid et al., 2018; Majid & Burenhult, 2014; Majid & Kruspe, 2018), but there are also notable differences in the specific linguistic strategies used to describe smells across cultures (see also O'Meara & Majid, 2016; Wnuk & Majid, 2014). So while English speakers

default to talking about odours by referring to their source (e.g., *smells like banana*), Jahai speakers—a hunter-gatherer community residing in the Malay Peninsula—have a dedicated lexicon of a dozen or more words to indicate distinct smell qualities (Majid & Burenhult, 2014): for example, *haʔɛ̃t* is the word for the common smell of tiger, shrimp paste, sap of rubber tree, as well as rotten meat; whereas *pʔus* is the smell of old dwellings, mushrooms, stale food, and some species of hornbill. Since these words refer solely to an olfactory quality, it is expected they would strongly activate odour representations, similar to how Japanese pain mimetics activate pain experiences (cf. Osaka et al., 2004).

As well as a qualitatively different odour vocabulary, there are other differences between these communities and modern industrialized cultures. They have been characterized as "smell cultures" because olfaction plays a strong role in day-to-day activities, as well as belief systems and ideology (Burenhult & Majid, 2011). Having a distinct lexicon and using odour language more frequently, as well as thinking about odours more in everyday life, is likely to make mental simulation of olfaction more relevant and necessary. It is an open question then whether cross-cultural differences in language and culture can affect mental simulation of the lower senses. Exploring differences across cultures may help elucidate the boundary conditions in the grounding of the lower senses, and more broadly reveal the potential connections between human language and perception (Majid & Levinson, 2011).

8. Conclusion

From a grounded perspective, language related to the senses of touch, taste, and smell has been comparatively neglected. Nevertheless, there are enough studies that when considered together they begin to paint a picture of how language for these senses is grounded in sensorimotor experience. At first glance, there appears to be behavioural evidence that perceptual stimuli can affect related conceptual processing (e.g., Boddy et al., 2016; Connell et al., 2012); and vice versa, that language of the lower senses can affect perception in those modalities (e.g., Brunyé et al., 2012; Dillmann et al., 2000; Olofsson et al., 2012). However, these studies do not rule out the possibility that perceptual representations are being activated by strategic processes, such as mental imagery. Although brain imaging studies sometimes show activation of primary (e.g., Barros-Loscertales et al., 2012; González et al., 2006) and secondary sensory cortices (e.g., Goldberg et al., 2006a, 2006b; Pomp et al., 2018) to language of the lower senses, it is not clear whether these activations reflect mental simulation or mental imagery. If automatic activation only goes as far as secondary regions, this suggests mental simulation of the lower senses is schematic and abstracted. In order to compensate for the lack of detail in mental simulations for taste and smell in particular, we suggest crossmodal compensation in associated domains, such a colour, action, or emotion, may be utilized to a greater extent.

Much remains to be learned about the automaticity and specificity of mental simulation for the lower senses. A particularly fruitful angle for future explorations would be to examine in detail different types of experience, such as that associated with expertise and cross-cultural variation. For now, the evidence from brain imaging and behavioural studies suggests the lower senses are not mentally simulated as deeply as the "higher senses" of vision and audition, calling for a rethink of the limits of grounded language.

Notes

1. The interaction between modality and switch-type (switch vs. no-switch) was marginally significant, $F(2, 148) = 2.55$, $p = .08$, $n_p^2 = .033$. Follow-up t-tests found a difference between switch and no-switch trials for auditory, $t(74) = 2.34$, $p = .02$; and visual $t(74) = 2.75$, $p = .007$ items, but not tactile ones, $t(74) = −.4$, $p = .69$. Data kindly shared by the authors.
2. The interaction between modality and switch-type (switch vs. no-switch) was marginally significant, $F(2, 118) = 2.43$, $p = .09$, $n_p^2 = .040$. Follow-up t-tests found a switch cost for auditory items, $t(59) = 3.17$, $p = .002$; but not visual $t(59) = .64$, $p = .53$ items, or tactile ones, $t(59) = −.24$, $p = .81$. Data kindly shared by the authors.

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References

Ackerman, D. (1990). *A natural history of the senses*. London, UK: Vintage Books.

Ackerman, J. M., Nocera, C. C., & Bargh, J. A. (2010). Incidental haptic sensations influence social judgments and decisions. *Science*, 328(5986), 1712–1715. doi:10.1126/science.1189993

Aguirre, G. K. (2003). *Functional imaging in behavioral neurology and cognitive neuropsychology. In behavioral neurology and cognitive neuropsychology*. New York: McGraw-Hill.

Anderson, M. L. (2010). Neural reuse: A fundamental organizational principle of the brain. *Behavioral and Brain Sciences*, 33(04), 245–266. doi:10.1017/S0140525X10000853

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. doi:10.1111/bjop.12050

Arshamian, A., Iannilli, E., Gerber, J. C., Willander, J., Persson, J., Seo, H.-S., … Larsson, M. (2013). The functional neuroanatomy of odor evoked autobiographical memories cued by odors and words. *Neuropsychologia*, 51(1), 123–131. doi:10.1016/j.neuropsychologia.2012.10.023

Arshamian, A., & Larsson, M. (2014). Same same but different: The case of olfactory imagery. *Frontiers in Psychology*, 5(34), 1–8.

Ashton, M. C., Pilkington, A. C., & Lee, K. (2014). Do prosocial people prefer sweet-tasting foods? An attempted replication of Meier, Moeller, Riemer-Peltz, and Robinson (2012). *Journal of Research in Personality*, 52, 42–46. doi:10.1016/j.jrp.2014.06.006

Auvray, M., Myin, E., & Spence, C. (2010). The sensory-discriminative and affective-motivational aspects of pain. *Neuroscience & Biobehavioral Reviews*, 34(2), 214–223. doi:10.1016/j.neubiorev.2008.07.008

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

Backhouse, A. E. (1994). *The lexical field of taste: A semantic study of Japanese taste terms*. Cambridge; New York, N.Y., USA: Cambridge University Press.

Bak, T. H., O'Donovan, D. G., Xuereb, J. H., Boniface, S., & Hodges, J. R. (2001). Selective impairment of verb processing associated with pathological changes in Brodmann areas 44 and 45 in the motor neurone disease–dementia–aphasia syndrome. *Brain*, 124(1), 103–120. doi:10.1093/brain/124.1.103

Bargh, J. A., & Shalev, I. (2012). The substitutability of physical and social warmth in daily life. *Emotion*, 12(1), 154–162. doi:10.1037/a0023527

Barros-Loscertales, A., Gonzalez, J., Pulvermuller, F., Ventura-Campos, N., Bustamante, J. C., Costumero, V., … Avila, C. (2012). Reading Salt activates gustatory brain regions: fMRI evidence for semantic grounding in a novel sensory modality. *Cerebral Cortex*, 22(11), 2554–2563. doi:10.1093/cercor/bhr324

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

Barsalou, L. W. (2003). Abstraction in perceptual symbol systems. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 358(1435), 1177–1187. doi:10.1098/rstb.2003.1319

Barsalou, L. W. (2016). On staying grounded and avoiding quixotic dead ends. *Psychonomic Bulletin & Review*, 23(4), 1122–1142. doi:10.3758/s13423-016-1028-3

Bechara, A., Damasio, H., & Damasio, A. (2000). Emotion, decision making and the orbitofrontal cortex. *Cerebral Cortex*, 10(3), 295–307. doi:10.1093/cercor/10.3.295

Bedny, M., & Caramazza, A. (2011). Perception, action, and word meanings in the human brain: The case from action verbs: Word meanings and sensory experience. *Annals of the New York Academy of Sciences*, 1224(1), 81–95. doi:10.1111/j.1749-6632.2011.06013.x

Beilock, S. L., Lyons, I. M., Mattarella-Micke, A., Nusbaum, H. C., & Small, S. L. (2008). Sports experience changes the neural processing of action language. *Proceedings of the National Academy of Sciences*, 105(36), 13269–13273. doi:10.1073/pnas.0803424105

Bensafi, M., Porter, J., Pouliot, S., Mainland, J., Johnson, B., Zelano, C., … Sobel, N. (2003). Olfactomotor activity during imagery mimics that during perception. *Nature Neuroscience*, 6(11), 1142–1144. doi:10.1038/nn1145

Bensafi, M., Pouliot, S., & Sobel, N. (2005). Odorant-specific patterns of sniffing during imagery distinguish 'bad' and 'good' olfactory imagers. *Chemical Senses*, 30(6), 521–529. doi:10.1093/chemse/bji045

Bensafi, M., Sobel, N., & Khan, R. M. (2007). Hedonic-specific activity in piriform cortex during odor imagery mimics that during odor perception. *Journal of Neurophysiology*, 98(6), 3254–3262. doi:10.1152/jn.00349.2007

Bergen, B., Lindsay, S., Matlock, T., & Narayanan, S. (2007). Spatial and linguistic aspects of visual imagery in sentence comprehension. *Cognitive Science: A Multidisciplinary Journal*, 31(5), 733–764. doi:10.1080/03640210701530748

Bergman, P., Ho, H.-N., Koizumi, A., Tajadura-Jiménez, A., & Kitagawa, N. (2015). The pleasant heat? Evidence for thermal-emotional implicit associations occurring with semantic and physical thermal stimulation. *Cognitive Neuroscience*, 6(1), 24–30. doi:10.1080/17588928.2014.988132

Boddy, P., Paz-Alonso, K., & Yee, E. (2016). *Does smelling pine cones make it harder to think about strawberries?* Presented at the Annual meeting of the Psychonomic Society, Boston.

Boesveldt, S., & de Graaf, K. (2017). The differential role of smell and taste for eating behavior. *Perception*, 46(3–4), 307–319. doi:10.1177/0301006616685576

Bonch-Osmolovskaya, A., Rakhilina, E., & Reznikova, T. (2009). Conceptualization of pain: A database for lexical typology. *Logic, Language, and Computation*, 5422, 110–123. doi:10.1007/978-3-642-00665-4_10

Borelli, E., Crepaldi, D., Porro, C. A., & Cacciari, C. (2018). The psycholinguistic and affective structure of words conveying pain. *PLOS ONE*, 13(6), e0199658. doi:10.1371/journal.pone.0199658

Borhani, K., Làdavas, E., Fotopoulou, A., & Haggard, P. (2017). "Lacking warmth": Alexithymia trait is related to warm-specific thermal somatosensory processing. *Biological Psychology*, 128, 132–140. doi:10.1016/j.biopsycho.2017.07.012

Brunyé, T. T., Walters, E. K., Ditman, T., Gagnon, S. A., Mahoney, C. R., & Taylor, H. A. (2012). The fabric of thought: Priming tactile properties during reading influences direct tactile perception. *Cognitive Science*, *36*(8), 1449–1467. doi:10.1111/j.1551-6709.2012.01268.x

Buck, C. D. (1949). *A dictionary of selected synonyms in the principal Indo-European languages: A contribution to the history of ideas*. Chicago: University of Chicago Press.

Burenhult, N., & Majid, A. (2011). Olfaction in Aslian ideology and language. *The Senses & Society*, *6*(1), 19–29. doi:10.2752/174589311X12893982233597

Bushdid, C., Magnasco, M. O., Vosshall, L. B., & Keller, A. (2014). Humans can discriminate more than 1 trillion olfactory stimuli. *Science*, *343*(6177), 1370–1372. doi:10.1126/science.1249168

Cain, W. S. (1979). To know with the nose: Keys to odor identification. *Science*, *203*(4379), 467–470. doi:10.1126/science.760202

Caramazza, A., Anzellotti, S., Strnad, L., & Lingnau, A. (2014). Embodied cognition and mirror neurons: A critical assessment. *Annual Review of Neuroscience*, *37*(1), 1–15. doi:10.1146/annurev-neuro-071013-013950

Casasanto, D. (2009). Embodiment of abstract concepts: Good and bad in right- and left-handers. *Journal of Experimental Psychology: General*, *138*(3), 351–367. doi:10.1037/a0015854

Chabris, C. F., Heck, P. R., Mandart, J., Benjamin, D. J., & Simons, D. J. (2019). No evidence that experiencing physical warmth promotes interpersonal warmth. *Social Psychology*, *50*(2), 127–132. doi:10.1027/1864-9335/a000361

Chamberlain, A. F. (1903). Primitive taste words. *American Journal of Psychology*, *14*(3/4), 146–153.

Chan, K. Q., Tong, E. M. W., Tan, D. H., & Koh, A. H. Q. (2013). What do love and jealousy taste like? *Emotion*, *13*(6), 1142–1149. doi:10.1037/a0033758

Chao, L. L., & Martin, A. (1999). Cortical regions associated with perceiving, naming, and knowing about colors. *Journal of Cognitive Neuroscience*, *11*(1), 25–35. doi:10.1162/089892999563229

Chatterjee, A. (2010). Disembodying cognition. *Language and Cognition*, *2*(1), 79–116.

Chen, I.-H., Zhao, Q., Long, Y., Lu, Q., & Huang, C.-R. (2019). Mandarin Chinese modality exclusivity norms. *PLOS ONE*, *14*(2), e0211336. doi:10.1371/journal.pone.0211336

Chow, H. M., Mar, R. A., Xu, Y., Liu, S., Wagage, S., & Braun, A. R. (2015). Personal experience with narrated events modulates functional connectivity within visual and motor systems during story comprehension: Effect of experience on functional connectivity. *Human Brain Mapping*, *36*(4), 1494–1505. doi:10.1002/hbm.22718

Christensen, C. M. (1983). Effects of color on aroma, flavor and texture judgments of foods. *Journal of Food Science*, *48*(3), 787–790. doi:10.1111/j.1365-2621.1983.tb14899.x

Citron, F. M. M., & Goldberg, A. E. (2014). Metaphorical sentences are more emotionally engaging than their literal counterparts. *Journal of Cognitive Neuroscience*, *26*(11), 2585–2595. doi:10.1162/jocn_a_00654

Classen, C. (1997). Foundations for an anthropology of the senses. *International Social Science Journal*, *49*(153), 401–412. doi:10.1111/j.1468-2451.1997.tb00032.x

Classen, C., Howes, D., & Synnott, A. (1994). *Aroma: The cultural history of smell*. London: Routledge.

Connell, L., & Lynott, D. (2010). Look but don't touch: Tactile disadvantage in processing modality-specific words. *Cognition*, *115*(1), 1–9. doi:10.1016/j.cognition.2009.10.005

Connell, L., Lynott, D., & Banks, B. (2018). Interoception: The forgotten modality in perceptual grounding of abstract and concrete concepts. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *373*(1752), 20170143. doi:10.1098/rstb.2017.0143

Connell, L., Lynott, D., & Dreyer, F. (2012). A functional role for modality-specific perceptual systems in conceptual representations. *PLoS ONE*, *7*(3), e33321. doi:10.1371/journal.pone.0033321

Craig, A. (2003). A new view of pain as a homeostatic emotion. *Trends in Neurosciences*, *26*(6), 303–307. doi:10.1016/S0166-2236(03)00123-1

Croijmans, I., & Majid, A. (2015). Odor naming is difficult, even for wine and coffee experts. *Proceedings of the 37th Annual Conference of the Cognitive Science Society*. Presented at the CogSci 2015, Pasadena, CA.

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*.

Cytowic, R. E. (1995). Synesthesia: Phenomenology and neuropsychology. *Psyche*, *2*(10), 2–10.

de Araujo, I. E., Rolls, E. T., Velazco, M. I., Margot, C., & Cayeux, I. (2005). Cognitive modulation of olfactory processing. *Neuron*, *46*(4), 671–679. doi:10.1016/j.neuron.2005.04.021

de la Vega, I., de Filippis, M., Lachmair, M., Dudschig, C., & Kaup, B. (2012). Emotional valence and physical space: Limits of interaction. *Journal of Experimental Psychology: Human Perception and Performance*, *38*(2), 375–385. doi:10.1037/a0024979

Delon-Martin, C., Plailly, J., Fonlupt, P., Veyrac, A., & Royet, J.-P. (2013). Perfumers' expertise induces structural reorganization in olfactory brain regions. *NeuroImage*, *68*, 55–62. doi:10.1016/j.neuroimage.2012.11.044

Derbyshire, S. W. G., Whalley, M. G., Stenger, V. A., & Oakley, D. A. (2004). Cerebral activation during hypnotically induced and imagined pain. *NeuroImage*, *23*(1), 392–401. doi:10.1016/j.neuroimage.2004.04.033

Desai, R. H., Herter, T., Riccardi, N., Rorden, C., & Fridriksson, J. (2015). Concepts within reach: Action performance predicts action language processing in stroke. *Neuropsychologia*, *71*, 217–224. doi:10.1016/j.neuropsychologia.2015.04.006

Desai, R. H., Reilly, M., & van Dam, W. (2018). The multifaceted abstract brain. *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences*, *373*(1752). https://doi.org/10.1098/rstb.2017.0122

de Valk, J. M., Wnuk, E., Huisman, J. L. A., & Majid, A. (2017). Odor–color associations differ with verbal descriptors for odors: A comparison of three linguistically diverse groups.

Psychonomic Bulletin & Review, *24*(4), 1171–1179. doi:10.3758/s13423-016-1179-2

de Vignemont, F. (2017). Pain and touch. *The Monist*, *100*(4), 465–477. doi:10.1093/monist/onx022

de Vignemont, F., & Massin, O. (2015). Touch. In M. Matthen (Ed.), *Touch* (pp. 294–314). doi:10.1093/oxfordhb/9780199600472.013.017.

Dillmann, J., Miltner, W. H. R., & Weiss, T. (2000). The influence of semantic priming on event-related potentials to painful laser-heat stimuli in humans. *Neuroscience Letters*, *4*, 53–56. doi:10.1016/S0304-3940(00)00957-5

Dingemanse, M., & Majid, A. (2012). *The semantic structure of sensory vocabulary in an African language*. 300–305.

Dove, G. (2009). Beyond perceptual symbols: A call for representational pluralism. *Cognition*, *110*(3), 412–431. doi:10.1016/j.cognition.2008.11.016

Eck, J., Richter, M., Straube, T., Miltner, W. H. R., & Weiss, T. (2011). Affective brain regions are activated during the processing of pain-related words in migraine patients. *Pain*, *152*(5), 1104–1113. doi:10.1016/j.pain.2011.01.026

Engen, T. (1987). Remembering odors and their names. *American Scientist*, *75*(5), 497–503.

Estes, Z., Verges, M., & Barsalou, L. W. (2008). Head up, foot down: Object words orient attention to the objects' typical location. *Psychological Science*, *19*(2), 93–97. doi:10.1111/j.1467-9280.2008.02051.x

Fernandino, L., Conant, L. L., Binder, J. R., Blindauer, K., Hiner, B., Spangler, K., & Desai, R. H. (2013). Where is the action? Action sentence processing in Parkinson's disease. *Neuropsychologia*, *51*(8), 1510–1517. doi:10.1016/j.neuropsychologia.2013.04.008

Ferreira, F., Engelhardt, P. E., & Jones, M. W. (2009). Good enough language processing: A satisficing approach. *Proceedings of the 31st Annual Conference of the Cognitive Science Society. Austin: Cognitive Science Society*.

Fetterman, A. K., Wilkowski, B. M., & Robinson, M. D. (2018). On feeling warm and being warm: Daily perceptions of physical warmth fluctuate with interpersonal warmth. *Social Psychological and Personality Science*, *9*(5), 560–567. doi:10.1177/1948550617712032

Gescheider, G. A. (1997). *Psychophysics: The fundamentals*. Mahwah, NJ: Lawrence Erlbaum.

Gilead, M., Gal, O., Polak, M., & Cholow, Y. (2015). The role of nature and nurture in conceptual metaphors: The case of gustatory priming. *Social Psychology*, *46*(3), 167–173. doi:10.1027/1864-9335/a000238

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review*, *9*(3), 558–565. doi:10.3758/BF03196313

Goldberg, R. F., Perfetti, C. A., & Schneider, W. (2006a). Distinct and common cortical activations for multimodal semantic categories. *Cognitive, Affective, & Behavioral Neuroscience*, *6*(3), 214–222. doi:10.3758/CABN.6.3.214

Goldberg, R. F., Perfetti, C. A., & Schneider, W. (2006b). Perceptual knowledge Retrieval activates sensory brain regions. *Journal of Neuroscience*, *26*(18), 4917–4921. doi:10.1523/JNEUROSCI.5389-05.2006

González, J., Barros-Loscertales, A., Pulvermüller, F., Meseguer, V., Sanjuán, A., Belloch, V., & Ávila, C. (2006). Reading cinnamon activates olfactory brain regions. *NeuroImage*, *32*(2), 906–912. doi:10.1016/j.neuroimage.2006.03.037

Grabenhorst, F., Rolls, E. T., & Bilderbeck, A. (2008). How cognition modulates affective responses to taste and flavor: Top-down influences on the orbitofrontal and pregenual cingulate cortices. *Cerebral Cortex*, *18*(7), 1549–1559. doi:10.1093/cercor/bhm185

Gu, X., & Han, S. (2007). Neural substrates underlying evaluation of pain in actions depicted in words. *Behavioural Brain Research*, *181*(2), 218–223. doi:10.1016/j.bbr.2007.04.008

Han, P., Croy, I., Raue, C., Bensafi, M., Larsson, M., Cavazzana, A., & Hummel, T. (2019). Neural processing of odor-associated words: An fMRI study in patients with acquired olfactory loss. *Brain Imaging and Behavior*. doi:10.1007/s11682-019-00062-2.

Hanks, A. S., Just, D. R., & Brumberg, A. (2016). Marketing vegetables in elementary school cafeterias to increase uptake. *Pediatrics*, *138*(2), e20151720. doi:10.1542/peds.2015-1720

Hauk, O., Johnsrude, I., & Pulvermüller, F. (2004). Somatotopic representation of action words in human motor and pre-motor cortex. *Neuron*, *41*(2), 301–307. doi:10.1016/S0896-6273(03)00838-9

Hauk, O., & Pulvermüller, F. (2004). Neurophysiological distinction of action words in the fronto-central cortex. *Human Brain Mapping*, *21*(3), 191–201. doi:10.1002/hbm.10157

Herz, R. S. (2003). The effect of verbal context on olfactory perception. *Journal of Experimental Psychology: General*, *132*(4), 595–606. doi:10.1037/0096-3445.132.4.595

Herz, R. S., & Clef, J. v. (2001). The influence of verbal labeling on the perception of odors: Evidence for olfactory illusions? *Perception*, *30*(3), 381–391. doi:10.1068/p3179

Ho, H.-N., Van Doorn, G. H., Kawabe, T., Watanabe, J., & Spence, C. (2014). Colour-temperature correspondences: When reactions to thermal stimuli are influenced by colour. *PLoS One*, *9*(3), e91854. doi:10.1371/journal.pone.0091854

Hoenig, K., Müller, C., Herrnberger, B., Sim, E.-J., Spitzer, M., Ehret, G., & Kiefer, M. (2011). Neuroplasticity of semantic representations for musical instruments in professional musicians. *NeuroImage*, *56*(3), 1714–1725. doi:10.1016/j.neuroimage.2011.02.065

Hombert, J.-M. (1992). Terminologie des odeurs dans quelques langues du Gabon. *Pholia*, *7*, 61–63.

Howes, D. (2003). *Sensual relations: Engaging the senses in culture and social theory*. Ann Arbor, Michigan: University of Michigan Press.

Iatropoulos, G., Herman, P., Lansner, A., Karlgren, J., Larsson, M., & Olofsson, J. K. (2018). The language of smell: Connecting linguistic and psychophysical properties of odor descriptors. *Cognition*, *178*, 37–49. doi:10.1016/j.cognition.2018.05.007

IJzerman, H., & Semin, G. R. (2009). The thermometer of social relations: Mapping social proximity on temperature. *Psychological Science*, *20*(10), 1214–1220. doi:10.1111/j.1467-9280.2009.02434.x

Iwasaki, N., Vinson, D., & Vigliocco, G. (2007). How does it hurt," kiri-kiri" or" siku-siku"? Japanese mimetic words of pain

perceived by Japanese speakers and English speakers. In M. Minami (Ed.), *Applying theory and research to learning Japanese as a foreign language* (pp. 2–19). Newcastle: Cambridge Scholars Publishing.

Kammers, M. P. M., Rose, K., & Haggard, P. (2011). Feeling numb: Temperature, but not thermal pain, modulates feeling of body ownership. *Neuropsychologia*, *49*(5), 1316–1321. doi:10.1016/j.neuropsychologia.2011.02.039

Kaschak, M. P., Madden, C. J., Therriault, D. J., Yaxley, R. H., Aveyard, M., Blanchard, A. A., & Zwaan, R. A. (2005). Perception of motion affects language processing. *Cognition*, *94*(3), B79–B89. doi:10.1016/j.cognition.2004.06.005

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. doi:10.1207/s15516709cog0000_54

Kemmerer, D. (2015). Are the motor features of verb meanings represented in the precentral motor cortices? Yes, but within the context of a flexible, multilevel architecture for conceptual knowledge. *Psychonomic Bulletin & Review*, *22*(4), 1068–1075. doi:10.3758/s13423-014-0784-1

Kemmerer, D. (2019). The perspective from semantic typology. In *Concepts in the brain: The view from cross-linguistic diversity* (pp. 3–28). Oxford: Oxford University Press.

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. doi: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. doi:10.1523/JNEUROSCI.3579-08.2008

Kikuchi, S., Kubota, F., Nisijima, K., Washiya, S., & Kato, S. (2005). Cerebral activation focusing on strong tasting food: A functional magnetic resonance imaging study. *NeuroReport*, *16*(3), 281–283. doi:10.1097/00001756-200502280-00016

Kita, S. (1997). Two-dimensional semantic analysis of Japanese mimetics. *Linguistics*, *35*(2), 379–416. doi:10.1515/ling.1997.35.2.379

Knost, B., Flor, H., Braun, C., & Birbaumer, N. (1997). Cerebral processing of words and the development of chronic pain. *Psychophysiology*, *34*, 474–481. doi:10.1111/j.1469-8986.1997.tb02392.x

Kobayashi, M., Sasabe, T., Shigihara, Y., Tanaka, M., & Watanabe, Y. (2011). Gustatory imagery reveals functional connectivity from the prefrontal to insular cortices traced with magnetoencephalography. *PLoS ONE*, *6*(7), e21736. doi:10.1371/journal.pone.0021736

Koptjevskaja-Tamm, M. (Ed.). (2015). *The linguistics of temperature* (Vol. 107). Amsterdam: John Benjamins Publishing Company.

Kousta, S.-T., Vigliocco, G., Vinson, D. P., Andrews, M., & Del Campo, E. (2011). The representation of abstract words: Why emotion matters. *Journal of Experimental Psychology: General*, *140*(1), 14–34. doi:10.1037/a0021446

Kurby, C. A., & Zacks, J. M. (2013). The activation of modality-specific representations during discourse processing. *Brain and Language*, *126*(3), 338–349. doi:10.1016/j.bandl.2013.07.003

Lacey, S., Stilla, R., & Sathian, K. (2012). Metaphorically feeling: Comprehending textural metaphors activates somatosensory cortex. *Brain and Language*, *120*(3), 416–421. doi:10.1016/j.bandl.2011.12.016

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. doi:10.1111/cogs.12174

Lee, S. W. S. (2016). Multimodal priming of abstract constructs. *Current Opinion in Psychology*, *12*, 37–44. doi:10.1016/j.copsyc.2016.04.016

Lee, D. S., Kim, E., & Schwarz, N. (2015). Something smells fishy: Olfactory suspicion cues improve performance on the Moses illusion and Wason rule discovery task. *Journal of Experimental Social Psychology*, *59*, 47–50. doi:10.1016/j.jesp.2015.03.006

Lee, S. W. S., & Schwarz, N. (2012). Bidirectionality, mediation, and moderation of metaphorical effects: The embodiment of social suspicion and fishy smells. *Journal of Personality and Social Psychology*, *103*(5), 737–749. doi:10.1037/a0029708

Levinson, S. C. (2012). The original sin of cognitive science. *Topics in Cognitive Science*, *4*(3), 396–403. doi:10.1111/j.1756-8765.2012.01195.x

Levinson, S. C., & Majid, A. (2014). Differential ineffability and the senses. *Mind & Language*, *29*(4), 407–427. doi:10.1111/mila.12057

Lorig, T. S. (1999). On the similarity of odor and language perception. *Neuroscience & Biobehavioral Reviews*, *23*(3), 391–398. doi:10.1016/S0149-7634(98)00041-4

Louwerse, M. M. (2011). Symbol interdependency in symbolic and embodied cognition. *Topics in Cognitive Science*, *3*(2), 273–302. doi:10.1111/j.1756-8765.2010.01106.x

Louwerse, M., & Connell, L. (2011). A taste of words: Linguistic context and perceptual simulation predict the modality of words. *Cognitive Science*, *35*(2), 381–398. doi:10.1111/j.1551-6709.2010.01157.x

Louwerse, M. M., & Jeuniaux, P. (2010). The linguistic and embodied nature of conceptual processing. *Cognition*, *114*(1), 96–104.

Ludwig, V. U., & Simner, J. (2013). What colour does that feel? Tactile–visual mapping and the development of cross-modality. *Cortex*, *49*(4), 1089–1099. doi:10.1016/j.cortex.2012.04.004

Luzzi, S., Snowden, J. S., Neary, D., Coccia, M., Provinciali, L., & Lambon Ralph, M. A. (2007). Distinct patterns of olfactory impairment in Alzheimer's disease, semantic dementia, frontotemporal dementia, and corticobasal degeneration. *Neuropsychologia*, *45*(8), 1823–1831. doi:10.1016/j.neuropsychologia.2006.12.008

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

Lynott, D., & Connell, L. (2013). Modality exclusivity norms for 400 nouns: The relationship between perceptual experience and surface word form. *Behavior Research Methods*, *45*(2), 516–526. doi:10.3758/s13428-012-0267-0

Lynott, D., Corker, K. S., Connell, L., & O'Brien, K. S. (2017). The effect of haptic and ambient temperature experience on pro-social behavior. *Archives of Scientific Psychology*, *5*, 10–18. doi:10.1037/arc0000031

Lynott, D., Corker, K. S., Wortman, J., Connell, L., Donnellan, M. B., & Lucas, R. E. (2014). Replication of '"experiencing physical warmth promotes interpersonal warmth"' by Williams and Bargh. *Social Psychology*, *45*(7), 216–222. doi:10.1027/1864-9335/a000187

Lyons, I. M., Mattarella-Micke, A., Cieslak, M., Nusbaum, H. C., Small, S. L., & Beilock, S. L. (2010). The role of personal experience in the neural processing of action-related language. *Brain and Language*, *112*(3), 214–222. doi:10.1016/j.bandl.2009.05.006

Macaluso, E., Frith, C. D., & Driver, J. (2000). Modulation of human visual cortex by crossmodal spatial attention. *Science*, *289*(5482), 1206–1208. doi:10.1126/science.289.5482.1206

Magee, H. (2009). *Talking about taste: How the description of food means and does* (BA thesis) Retrieved from http://hdl.handle.net/10066/10174.

Mahon, B. Z., & Caramazza, A. (2008). A critical look at the embodied cognition hypothesis and a new proposal for grounding conceptual content. *Journal of Physiology-Paris*, *102*(1–3), 59–70. doi:10.1016/j.jphysparis.2008.03.004

Mainland, J., & Sobel, N. (2006). The sniff is part of the olfactory percept. *Chemical Senses*, *31*(2), 181–196. doi:10.1093/chemse/bjj012

Majid, A., & Burenhult, N. (2014). Odors are expressible in language, as long as you speak the right language. *Cognition*, *130*(2), 266–270. doi:10.1016/j.cognition.2013.11.004

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. doi:10.1098/rstb.2017.0139

Majid, A., & Kruspe, N. (2018). Hunter-gatherer olfaction is special. *Current Biology*, *28*(3), 409–413.e2. doi:10.1016/j.cub.2017.12.014

Majid, A., & Levinson, S. C. (2008). Language does provide support for basic tastes. *Behavioral and Brain Sciences*, *31*(01), 86–87. doi:10.1017/S0140525X08003476

Majid, A., & Levinson, S. C. (2011). The senses in language and culture. *The Senses and Society*, *6*(1), 5–18. doi:10.2752/174589311X12893982233551

Majid, A., Roberts, S. G., Cilissen, L., Emmorey, K., Nicodemus, B., Woll, B., … Levinson, S. C. (2018). Differential coding of perception in the world's languages. *Proceedings of the National Academy of Sciences*.

Majid, A., Speed, L. J., Croijmans, I., & Arshamian, A. (2017). What makes a better smeller? *Perception*, *46*(3–4), 406–430. doi:10.1177/0301006616688224

Martin, A., Haxby, J. V., Lalonde, F. o. M., Wiggs, C. L., & Ungerleider, L. G. (1995). Discrete cortical regions associated with knowledge of color and knowledge of action. *Science*, *270*(5233), 102–105. doi:10.1126/science.270.5233.102

Meier, B. P., Moeller, S. K., Riemer-Peltz, M., & Robinson, M. D. (2012). Sweet taste preferences and experiences predict pro-social inferences, personalities, and behaviors. *Journal of Personality and Social Psychology*, *102*(1), 163–174. doi:10.1037/a0025253

Melzack, R. (1975). The McGill pain Questionnaire: Major properties and scoring methods. *Pain*, *1*(3), 277–299. doi:10.1016/0304-3959(75)90044-5

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

Meteyard, L., 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. doi:10.1016/j.cortex.2010.11.002

Meteyard, L., Zokaei, N., Bahrami, B., & Vigliocco, G. (2008). Visual motion interferes with lexical decision on motion words. *Current Biology*, *18*(17), R732–R733. doi:10.1016/j.cub.2008.07.016

Morey, R. D., Glenberg, A. M., Kaschak, M. P., Lakens, D., & Zwaan, R. A. (2018). *Testing the ACE effect. A pre-registered, multi-lab test of the Action-Sentence Compatibility Effect*. Presented at the Annual meeting of the Psychonomic Society, New Orleans.

Mukherjee, S., Kramer, T., & Kulow, K. (2017). The effect of spicy gustatory sensations on variety-seeking. *Psychology & Marketing*, *34*(8), 786–794. doi:10.1002/mar.21022

Myers, C. S. (1904). The taste-names of primitive peoples. *British Journal of Psychology*, *1*(2), 117.

Nakagawa, H. (2012). *The Importance of TASTE Verbs in Some Khoe Languages*, *50*(3), 395–420.

Nikendei, C., Dengler, W., Wiedemann, G., & Pauli, P. (2005). Selective processing of pain-related word stimuli in subclinical depression as indicated by event-related brain potentials. *Biological Psychology*, *70*(1), 52–60. doi:10.1016/j.biopsycho.2004.11.012

Olofsson, J. K., Bowman, N. E., & Gottfried, J. A. (2013). High and low roads to odor valence? A choice response-time study. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(5), 1205–1211. doi:10.1037/a0033682

Olofsson, J. K., Bowman, N. E., Khatibi, K., & Gottfried, J. A. (2012). A time-based account of the perception of odor objects and valences. *Psychological Science*, *23*(10), 1224–1232. doi:10.1177/0956797612441951

Olofsson, J. K., & Gottfried, J. A. (2015). The muted sense: Neurocognitive limitations of olfactory language. *Trends in Cognitive Sciences*, *19*(6), 314–321. doi:10.1016/j.tics.2015.04.007

O'Mahony, M., Goldenberg, M., Stedmon, J., & Alford, J. (1979). Confusion in the use of the taste adjectives "sour" and "bitter.". *Chemical Senses*, *4*(4), 301–318. doi:10.1093/chemse/4.4.301

O'Meara, C., & Majid, A. (2016). How changing lifestyles impact Seri smellscapes and smell language. *Anthropological Linguistics*, *58*(2), 107–131. doi:10.1353/anl.2016.0024

O'Meara, C., Speed, L. J., San Roque, L., & Majid, A. (2019). Perception metaphors: A view from diversity. In *Perception metaphors* (pp. 1–16). Amsterdam: Benjamins.

Osaka, N., Osaka, M., Morishita, M., Kondo, H., & Fukuyama, H. (2004). A word expressing affective pain activates the anterior cingulate cortex in the human brain: An fMRI study. *Behavioural Brain Research*, *153*(1), 123–127. doi:10.1016/j.bbr.2003.11.013

Osawa, Y., & Ellen, R. (2014). The cultural cognition of taste term conflation. *The Senses and Society*, *9*(1), 72–91. doi:10.2752/174589314X13834112761083

Ostarek, M., Joosen, D., Ishag, A., de Nijs, M., & Huettig, F. (2019). Are visual processes causally involved in "perceptual simulation" effects in the sentence-picture verification task? *Cognition*, *182*, 84–94. doi:10.1016/j.cognition.2018.08.017

Ostarek, M., & Vigliocco, G. (2017). Reading sky and seeing a cloud: On the relevance of events for perceptual simulation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *43*(4), 579–590. doi:10.1037/xlm0000318

Papies, E. K. (2013). Tempting food words activate eating simulations. *Frontiers in Psychology*, *4*. doi:10.3389/fpsyg.2013.00838

Pecher, D., van Dantzig, S., & Schifferstein, H. N. J. (2009). Concepts are not represented by conscious imagery. *Psychonomic Bulletin & Review*, *16*(5), 914–919. doi:10.3758/PBR.16.5.914

Pecher, D., Zeelenberg, R., & Barsalou, L. W. (2003). Verifying different-modality properties for concepts produces switching costs. *Psychological Science*, *14*(2), 119–124. doi:10.1111/1467-9280.t01-1-01429

Perniss, P., & Vigliocco, G. (2014). The bridge of iconicity: From a world of experience to the experience of language. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1651), 20130300–20130300. doi:10.1098/rstb.2013.0300

Peyron, R., Laurent, B., & García-Larrea, L. (2000). Functional imaging of brain responses to pain. A review and meta-analysis (2000). *Neurophysiologie Clinique/Clinical Neurophysiology*, *30*(5), 263–288. doi:10.1016/S0987-7053(00)00227-6

Plailly, J., Delon-Martin, C., & Royet, J.-P. (2012). Experience induces functional reorganization in brain regions involved in odor imagery in perfumers. *Human Brain Mapping*, *33*(1), 224–234. doi:10.1002/hbm.21207

Poldrack, R. A. (2011). Inferring mental states from neuroimaging data: From reverse inference to large-scale decoding. *Neuron*, *72*(5), 692–697. doi:10.1016/j.neuron.2011.11.001

Poldrack, R. (2006). Can cognitive processes be inferred from neuroimaging data? *Trends in Cognitive Sciences*, *10*(2), 59–63. doi:10.1016/j.tics.2005.12.004

Pomp, J., Bestgen, A.-K., Schulze, P., Müller, C. J., Citron, F. M. M., Suchan, B., & Kuchinke, L. (2018). Lexical olfaction recruits olfactory orbitofrontal cortex in metaphorical and literal contexts. *Brain and Language*, *179*, 11–21. doi:10.1016/j.bandl.2018.02.001

Pulvermüller, F. (2013). How neurons make meaning: Brain mechanisms for embodied and abstract-symbolic semantics. *Trends in Cognitive Sciences*, *17*(9), 458–470. doi:10.1016/j.tics.2013.06.004

Pulvermuller, F., & Hauk, O. (2006). Category-specific conceptual processing of color and form in left fronto-temporal cortex. *Cerebral Cortex*, *16*(8), 1193–1201. doi:10.1093/cercor/bhj060

Ren, D., Tan, K., Arriaga, X. B., & Chan, K. Q. (2015). Sweet love: The effects of sweet taste experience on romantic perceptions. *Journal of Social and Personal Relationships*, *32*(7), 905–921. doi:10.1177/0265407514554512

Reuter, K., Werning, M., Kuchinke, L., & Cosentino, E. (2017). Reading words hurts: The impact of pain sensitivity on people's ratings of pain-related words. *Language and Cognition*, *9*(03), 553–567. doi:10.1017/langcog.2016.29

Reznikova, T., Rakhilina, E., & Bonch-Osmolovskaya, A. (2012). Towards a typology of pain predicates. *Linguistics*, *50*(3), doi:10.1515/ling-2012-0015

Richter, M., Eck, J., Straube, T., Miltner, W. H. R., & Weiss, T. (2010). Do words hurt? *Brain Activation During the Processing of Pain-Related Words: Pain*, *148*(2), 198–205. doi:10.1016/j.pain.2009.08.009.

Richter, M., Schroeter, C., Puensch, T., Straube, T., Hecht, H., Ritter, A., … Weiss, T. (2014). Pain-related and negative semantic priming enhances perceived pain intensity. *Pain Research and Management*, *19*(2), 69–74. doi:10.1155/2014/425321

Ritter, A., Franz, M., Puta, C., Dietrich, C., Miltner, W., & Weiss, T. (2016). Enhanced brain responses to pain-related words in chronic Back pain patients and their Modulation by current pain. *Healthcare*, *4*(3), 54. doi:10.3390/healthcare4030054

Rolls, E. T. (2004). The functions of the orbitofrontal cortex. *Brain and Cognition*, *55*(1), 11–29. doi:10.1016/S0278-2626(03)00277-X

Rowbotham, S., Holler, J., Lloyd, D., & Wearden, A. (2012). How do we communicate about pain? A systematic analysis of the semantic contribution of co-speech gestures in pain-focused conversations. *Journal of Nonverbal Behavior*, *36*(1), 1–21. doi:10.1007/s10919-011-0122-5

Royet, J.-P., Plailly, J., Delon-Martin, C., Kareken, D. A., & Segebarth, C. (2003). fMRI of emotional responses to odors: Influence of hedonic valence and judgment, handedness, and gender. *NeuroImage*, *20*(2), 713–728. doi:10.1016/S1053-8119(03)00388-4

Rueschemeyer, S.-A., Pfeiffer, C., & Bekkering, H. (2010). Body schematics: On the role of the body schema in embodied lexical–semantic representations. *Neuropsychologia*, *48*(3), 774–781. doi:10.1016/j.neuropsychologia.2009.09.019

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. doi:10.1093/chemse/bjv078

San Roque, L., Kendrick, K. H., Norcliffe, E. J., Brown, P., Defina, R., Dingemanse, M., … Majid, A. (2015). Vision verbs dominate in conversation across cultures, but the ranking of non-visual verbs varies. *Cognitive Linguistics*, *26*, 31–60. doi:10.1515/cog-2014-0089

Schaefer, M., Cherkasskiy, L., Denke, C., Spies, C., Song, H., Malahy, S., … Bargh, J. A. (2018). Incidental haptic sensations influence judgment of crimes. *Scientific Reports*, 8(1), doi:10.1038/s41598-018-23586-x.

Schaefer, M., Denke, C., Heinze, H.-J., & Rotte, M. (2014). Rough primes and rough conversations: Evidence for a modality-specific basis to mental metaphors. *Social Cognitive and Affective Neuroscience*, 9(11), 1653–1659. doi:10.1093/scan/nst163

Semin, G. R., & de Groot, J. H. (2013). The chemical bases of human sociality. *Trends in Cognitive Sciences*. Retrieved from http://www.sciencedirect.com/science/article/pii/S1364661313001174

Sezille, C., Fournel, A., Rouby, C., Rinck, F., & Bensafi, M. (2014). Hedonic appreciation and verbal description of pleasant and unpleasant odors in untrained, trainee cooks, flavorists and perfumers. *Frontiers in Cognitive Science*, 5, 12. doi:10.3389/fpsyg.2014.00012.

Shepherd, G. M. (2004). The human sense of smell: Are we better than we think? *PLoS Biology*, 2(5), e146. doi:10.1371/journal.pbio.0020146

Shepherd, G. M. (2006). Smell images and the flavour system in the human brain. *Nature*, 444(7117), 316–321. doi:10.1038/nature05405

Si, K., & Jiang, Y. (2017). Bidirectional contrast effects between taste perception and simulation: A simulation-induced adaptation mechanism. *Journal of Consumer Psychology*, 27(1), 49–58. doi:10.1016/j.jcps.2016.04.002

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. doi:10.1093/cercor/bhi038

Simmons, W. K., Ramjee, V., Beauchamp, M. S., McRae, K., Martin, A., & Barsalou, L. W. (2007). A common neural substrate for perceiving and knowing about color. *Neuropsychologia*, 45(12), 2802–2810. doi:10.1016/j.neuropsychologia.2007.05.002

Smeets, P. A. M., Dagher, A., Hare, T. A., Kullmann, S., van der Laan, L. N., Poldrack, R. A., … Veldhuizen, M. G. (2019). Good practice in food-related neuroimaging. *The American Journal of Clinical Nutrition*, 109(3), 491–503. doi:10.1093/ajcn/nqy344

Sobel, N., Prabhakaran, V., Desmond, J. E., Glover, G. H., Goode, R. L., Sullivan, E. V., & Gabrieli, J. D. E. (1998). Sniffing and smelling: Separate subsystems in the human olfactory cortex. *Nature*, 392(6673), 282–286. doi:10.1038/32654

Sorabji, R. (1971). Aristotle on demarcating the five senses. *The Philosophical Review*, 80(1), 55–79. doi:10.2307/2184311

Speed, L. J., & Majid, A. (2017a). Dutch modality exclusivity norms: Simulating perceptual modality in space. *Behavior Research Methods*, 49(6), 2204–2218. doi:10.3758/s13428-017-0852-3

Speed, L. J., & Majid, A. (2018a). An exception to mental simulation: No evidence for embodied odor language. *Cognitive Science*, 42(4), 1146–1178. doi:10.1111/cogs.12593

Speed, L. J., & Majid, A. (2018b). Superior olfactory language and cognition in odor-color synaesthesia. *Journal of Experimental Psychology: Human Perception and Performance*, 44(3), 468–481.

Speed, L. J., van Dam, W. O., Hirath, P., Vigliocco, G., & Desai, R. H. (2017). Impaired comprehension of speed verbs in Parkinson's disease. *Journal of the International Neuropsychological Society*, 1–9. doi:10.1017/S1355617717000248.

Speed, L. J., van Dam, W. O, Vigliocco, G., & Desai, R. H. (2018). Movement speed affects speed language comprehension. *Proceedings of the 40th Annual Conference of the Cognitve Science Society*. Presented at the Wisconsin, MA. Wisconsin, MA: Cognitive Science Society.

Speed, L. J., & Vigliocco, G. (2014). Eye movements reveal the dynamic simulation of speed in language. *Cognitive Science*, 38(2), 367–382. doi:10.1111/cogs.12096

Spence, C., Levitan, C. A., Shankar, M. U., & Zampini, M. (2010). Does food color influence taste and flavor perception in humans? *Chemosensory Perception*, 3(1), 68–84. doi:10.1007/s12078-010-9067-z

Spence, C., Nicholls, M. E. R., & Driver, J. (2001a). The cost of expecting events in the wrong sensory modality. *Perception & Psychophysics*, 63(2), 330–336. doi:10.3758/BF03194473

Spence, C., Shore, D., & Klein, R. (2001b). Multisensory prior entry.. *Journal of Experimental Psychology. General*, 130(4), 799–832. doi:10.1037/0096-3445.130.4.799

Spence, C., Smith, B., & Auvray, M. (2015). Confusing tastes and flavours. In D. Stokes, M. Matthen, & S. Biggs (Eds.), *Perception and its modalities* (pp. 247–274). Oxford: Oxford University Press.

Stevens, S. S. (1975). *Psychophysics*. New York: Wiley.

Stokes, D., & Biggs, S. (2014). The dominance of the visual. In D. Stokes, M. Matthen, & S. Biggs (Eds.), *Perception and Its modalities* (pp. 350–378). doi:10.1093/acprof:oso/9780199832798.003.0015.

Tettamanti, M., Buccino, G., Saccuman, C. M., Gallese, V., Danna, M., Scifo, P., & Fazio, F. (2005). Listening to action-related sentences activates fronto-parietal motor circuits. *Journal of Cognitive Neuroscience*, 17(2), 273–281. doi:10.1162/0898929053124965

Tsakiris, M., & De Preester, H. (2018). *The interoceptive mind*. Oxford: Oxford University Press.

Tucker, M., & Ellis, R. (2004). Action priming by briefly presented objects. *Acta Psychologica*, 116(2), 185–203. doi:10.1016/j.actpsy.2004.01.004

Turner, B. O., Paul, E. J., Miller, M. B., & Barbey, A. K. (2018). Small sample sizes reduce the replicability of task-based fMRI studies. *Communications Biology*, 1(1), doi:10.1038/s42003-018-0073-z

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. doi:10.1001/jamainternmed.2017.1637

van Ackeren, M. J., Casasanto, D., Bekkering, H., Hagoort, P., & Rueschemeyer, S.-A. (2012). Pragmatics in action: Indirect requests engage theory of mind areas and the cortical motor network. *Journal of Cognitive Neuroscience*, 24(11), 2237–2247. doi:10.1162/jocn_a_00274

van Ackeren, M. J., & Rueschemeyer, S.-A. (2014). Cross-modal integration of lexical-semantic features during word processing: Evidence from oscillatory dynamics during EEG. *PLoS ONE*, 9(7), e101042. doi:10.1371/journal.pone.0101042

van Ackeren, M. J., Schneider, T. R., Musch, K., & Rueschemeyer, S.-A. (2014). Oscillatory neuronal activity reflects lexical-semantic feature integration within and across sensory modalities in distributed cortical networks. *Journal of Neuroscience*, 34(43), 14318–14323. doi:10.1523/JNEUROSCI. 0958-14.2014

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. doi:10. 1002/hbm.21365

van Dantzig, S., Pecher, D., Zeelenberg, R., & Barsalou, L. (2008). Perceptual processing affects conceptual processing. *Cognitive Science: A Multidisciplinary Journal*, 32(3), 579–590. doi:10.1080/03640210802035365

Veldhuizen, M. G., Bender, G., Constable, R. T., & Small, D. M. (2007). Trying to detect taste in a tasteless solution: Modulation of early gustatory cortex by attention to taste. *Chemical Senses*, 32(6), 569–581. doi:10.1093/chemse/bjm025

Vigliocco, G., Kousta, S.-T., Della Rosa, P. A., Vinson, D. P., Tettamanti, M., Devlin, J. T., & Cappa, S. F. (2014). The neural representation of abstract words: The role of emotion. *Cerebral Cortex*, 24(7), 1767–1777. doi:10.1093/cercor/bht025

Vigliocco, G., Meteyard, L., Andrews, M., & Kousta, S. (2009). Toward a theory of semantic representation. *Language and Cognition*, 1(02), 219–247. doi:10.1515/LANGCOG.2009.011

Vukovic, N., Fardo, F., & Shtyrov, Y. (2019). When words burn – language processing differentially modulates pain perception in typical and chronic pain populations. *Language and Cognition*, 1–15. doi:10.1017/langcog.2018.22.

Wang, X., Geng, L., Qin, J., & Yao, S. (2016). The potential relationship between spicy taste and risk seeking. *Judgment and Decision Making*, 11(6), 547–553.

Weiss, T., Miltner, W. H. R., & Dillmann, J. (2003). The influence of semantic priming on event-related potentials to painful laser-heat stimuli in migraine patients. *Neuroscience Letters*, 340(2), 135–138. doi:10.1016/S0304-3940(03)00103-4

Wheatley, T., Weisberg, J., Beauchamp, M. S., & Martin, A. (2005). Automatic priming of semantically related words reduces activity in the fusiform gyrus. *Journal of Cognitive Neuroscience*, 17(12), 1871–1885. doi:10.1162/089892905775008689

Wheeler, K. B., & Bergen, B. K. (2010). *Meaning in the palm of your hand. In Empirical and experimental methods in conceptual structure, Discourse, and language*. Stanford: CSLI.

Wierzbicka, A. (2012). Is pain a human universal? A cross-linguistic and cross-cultural perspective on pain. *Emotion Review*, 4(3), 307–317. doi:10.1177/1754073912439761

Willems, R. M., Hagoort, P., & Casasanto, D. (2010). Body-specific representations of action verbs: Neural evidence from right- and left-handers. *Psychological Science*, 21(1), 67–74. doi:10.1177/0956797609354072

Willems, R. M., Toni, I., Hagoort, P., & Casasanto, D. (2010). Neural dissociations between action verb understanding and motor imagery. *Journal of Cognitive Neuroscience*, 22(10), 2387–2400. doi:10.1162/jocn.2009.21386

Willems, R. M., & van Gerven, M. A. J. (2018). New fMRI methods for the study of language. In *Oxford Handbook of Psycholinguistics* (pp. 975–991). Oxford: Oxford University Press.

Williams, L. E., & Bargh, J. A. (2008). Experiencing physical warmth promotes interpersonal warmth. *Science*, 322(5901), 606–607. doi:10.1126/science.1162548

Wilson-Mendenhall, C. D., Henriques, A., Barsalou, L. W., & Barrett, L. F. (2019). Primary interoceptive cortex activity during simulated experiences of thebody. *Journal of Cognitive Neuroscience*, 31(2), 221–235. doi:10.1162/jocn_a_01346

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. doi:10.1080/23273798.2016.1193619

Winter, B., Perlman, M., & Majid, A. (2018). Vision dominates in perceptual language: English sensory vocabulary is optimized for usage. *Cognition*, 179, 213–220. doi:10.1016/j.cognition.2018.05.008

Winter, B., Perlman, M., Perry, L. K., & Lupyan, G. (2017). Which words are most iconic? Iconicity in English sensory words. *Interaction Studies*, 18(3), 443–464. doi:10.1075/is.18.3.07win

Wnuk, E., de Valk, J. M., Huisman, J. L. A., & Majid, A. (2017). Hot and cold smells: Odor-temperature associations across cultures. *Frontiers in Psychology*, 8. doi:10.3389/fpsyg.2017.01373

Wnuk, E., & Majid, A. (2014). Revisiting the limits of language: The odor lexicon of Maniq. *Cognition*, 131(1), 125–138. doi:10.1016/j.cognition.2013.12.008

Wortman, J., Donnellan, M. B., & Lucas, R. E. (2014). Can physical warmth (or coldness) predict trait loneliness? A replication of Bargh and Shalev (2012). *Archives of Scientific Psychology*, 2(1), 13–19. doi:10.1037/arc0000007

Xie, J., Lu, Z., Wang, R., & Cai, Z. G. (2016). Remember hard but think softly: Metaphorical effects of hardness/softness on cognitive functions. *Frontiers in Psychology*, 7, 1343. doi:10.3389/fpsyg.2016.01343

Xu, J. (2017). *"That's bitter!" culture specific effects of gustatory experience on judgments of fairness and advancement* (Masters dissertation). Winnipeg: University of Manitoba.

Yaxley, R. H., & Zwaan, R. A. (2007). Simulating visibility during language comprehension. *Cognition*, 105(1), 229–236. doi:10.1016/j.cognition.2006.09.003

Yee, E., & Thompson-Schill, S. L. (2016). Putting concepts into context. *Psychonomic Bulletin & Review*, 23(4), 1015–1027. doi:10.3758/s13423-015-0948-7

Yeomans, M. R., Chambers, L., Blumenthal, H., & Blake, A. (2008). The role of expectancy in sensory and hedonic evaluation: The case of smoked salmon ice-cream. *Food Quality and Preference*, 19(6), 565–573. doi:10.1016/j.foodqual.2008.02.009

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

Zelano, C., Mohanty, A., & Gottfried, J. A. (2011). Olfactory predictive codes and stimulus templates in piriform cortex. *Neuron*, 72(1), 178–187. doi:10.1016/j.neuron.2011.08.010

Zwaan, R. A. (2003). The Immersed Experiencer: Toward An embodied Theory Of language comprehension. *Psychology of Learning and Motivation*, 44, 35–62. doi:10.1016/S0079-7421(03)44002-4

Zwaan, R. A. (2014). Embodiment and language comprehension: Reframing the discussion. *Trends in Cognitive Sciences*, 18(5), 229–234. doi:10.1016/j.tics.2014.02.008

Zwaan, R. A., Madden, C. J., Yaxley, R. H., & Aveyard, M. (2004). Moving words: Dynamic representations in language comprehension. *Cognitive Science*, 28(4), 611–619. doi:10.1016/j.cogsci.2004.03.004.

Zwaan, R. A., & Pecher, D. (2012). Revisiting mental simulation in language comprehension: Six replication attempts. *PLOS ONE*, 7(12), e51382. doi:10.1371/journal.pone.0051382

Zwaan, R. A., Pecher, D., Paolacci, G., Bouwmeester, S., Verkoeijen, P., Dijkstra, K., & Zeelenberg, R. (2017). Participant Nonnaiveté and the reproducibility of cognitive psychology. *Psychonomic Bulletin & Review*, 25, 1968–1972. doi:10.3758/s13423-017-1348-y

Zwaan, R. A., Stanfield, R. A., & Yaxley, R. H. (2002). Language comprehenders mentally represent the shapes of objects. *Psychological Science*, 13(2), 168–171. doi:10.1111/1467-9280.00430

Zwaan, R. A., & Taylor, L. J. (2006). Seeing, acting, understanding: Motor resonance in language comprehension. *Journal of Experimental Psychology: General*, 135(1), 1–11. doi:10.1037/0096-3445.135.1.1