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Do We Know What We're Simulating? Information Loss on Transferring Unconscious Perceptual Simulation to Conscious Imagery

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Perceptual simulations are unconscious and automatic, whereas perceptual imagery is conscious and deliberate, but it is unclear how easily one can transfer perceptual information from unconscious to conscious awareness. We investigated whether it is possible to be aware of what one is mentally representing; that is, whether it is possible to consciously examine the contents of a perceptual simulation without information being lost. Studies 1 and 2 found that people cannot accurately evaluate the perceptual content of a representation unless attention is explicitly drawn to each modality individually. In particular, when asked to consider sensory experience as a whole, modality-specific auditory, gustatory, and haptic information is neglected, and olfactory and visual information distorted. Moreover, information loss is greatest for perceptually complex, multimodal simulations. Study 3 examined if such information loss leads to behavioral consequences by examining performance during lexical decision, a task whose semantic effects emerge from automatic access to the full potential of unconscious perceptual simulation. Results showed that modality-specific perceptual strength consistently outperformed modality-general sensory experience ratings in predicting latency and accuracy, which confirms that the effects of Studies 1 and 2 are indeed due to information being lost in the transfer to conscious awareness. These findings suggest that people indeed have difficulty in transferring perceptual information from unconscious simulation to conscious imagery. People cannot be aware of the full contents of a perceptual simulation because the act of bringing it to awareness leads to systematic loss of information.

Keywords: perceptual simulation, imagery, modality-specific perceptual strength, sensory experience ratings, lexical decision

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Grounded accounts of semantics hold that conceptual representations comprise simulations. The neural activation that arises during perceptual (and motor, affective, etc.) experience is partially captured and then replayed—or simulated—during language comprehension, problem solving, and other cognitive tasks that involve conceptual access (Barsalou, 1999; Connell & Lynott, 2014b; Glenberg, 1997; Wilson, 2002; Vigliocco, Meteyard, Andrews, & Kousta, 2009; Zwaan, 2004). Perceptual simulations are unconscious and automatic, in contrast to mental imagery which is conscious and deliberate. Indeed, mental imagery may be considered a special case of perceptual simulation, where the simulation is consciously inspected and manipulated in working memory (e.g., Barsalou, 2009; Moulton & Kosslyn, 2009). However, it is unclear whether perceptual simulations can move easily from unconscious to conscious representation. Are people capable of reliably reporting imagery from perceptual simulations? Or, in other words, can people be aware of everything they are simulating?

There are reasons to think that the transfer from unconscious simulation to conscious imagery might create some difficulties. First, working memory is necessarily limited and may not be able to contain the full extent of a perceptual simulation. By limited working memory, we do not mean a "magic number" of seven (Miller, 1956) or four (Cowan, 2010) items, but rather refer to a finite-capacity buffer that allows information from long-term memory to be integrated and manipulated (Baddeley, 2000; Ericsson & Kintsch, 1995). A situation model created during the reading of a novel, for example, may comprise a detailed perceptual simulation of the objects, entities, events, and goals inherent to the plot (Zwaan, 2004). The contents of working memory at a given point in time, though, are likely to be limited to objects that are close and visible rather than distant or occluded (Horton & Rapp, 2003; Morrow, Greenspan, & Bower, 1987), events that are ongoing rather than completed (Zwaan, 1996), and so on. In other words, some information in a perceptual simulation is likely to be lost when brought to working memory as imagery for conscious inspection. Second, people do not find it equally easy to deliberately generate imagery across all modalities (Connell & Lynott, 2012). In particular, people tend to have relatively little practice in imagining what something sounds, tastes, or feels like, which leads auditory, gustatory, and haptic information to be ignored or misinterpreted when rating the ease of generating imagery (i.e., imageability). It is possible that similar information loss may come into play any time that people attempt to transfer a conceptual

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representation from automatic, unconscious simulation to conscious awareness, whereby the auditory, gustatory, and haptic modalities are likely to be disfavored.

One way to differentiate between conscious and unconscious representation is to ask people to evaluate the representation in some way. The task of rating the extent of perceptual information in a concept such as *chair* requires participants to mentally represent the meaning of the word (i.e., unconscious simulation of perceptual, motor, situational, etc. experience of chairs) and to evaluate those aspects that relate to sensory experience (i.e., conscious imagery of how chairs look, feel, etc.). A number of different semantic variables have attempted to tap into the perceptual basis of conceptual representation, including concreteness and imageability (Paivio, Yuille, & Madigan, 1968), perceptual strength (Lynott & Connell, 2009, 2013), and sensory experience ratings (Juhasz & Yap, 2013). Of these, only the latter two explicitly examine the extent of perceptual information in concepts; concreteness ratings reflect separate decision criteria that are largely unrelated to perceptual information (Connell & Lynott, 2012), and imageability ratings reflect the ease of generating perceptual imagery rather than the extent of perceptual information therein.

Lynott and Connell's (2009, 2013) modality-specific ratings of perceptual strength asked people to rate the extent to which they experience a given concept (e.g., chair) by seeing, hearing, smelling, tasting, or feeling through touch, where each modality is rated separately on a scale from 0 (*not at all*) to 5 (*greatly*). Perceptual strength in the dominant modality (i.e., the maximum rating across all five modalities) is an effective predictor of lexical decision and naming performance, subsuming the effects of both concreteness and imageability ratings (Connell & Lynott, 2012). Juhasz and Yap's (2013) sensory experience ratings (SER) asked people to rate the degree of sensory experience evoked by a word, on a scale from 1 (*no sensory experience*) to 7 (*strong sensory experience*), where sensory experience was defined as an actual sensation (taste, touch, sight, sound, or smell) experienced by reading the word. Like perceptual strength, SER is a predictor of lexical decision and naming times above and beyond imageability (Juhasz, Yap, Dicke, Taylor, & Gullick, 2011; Juhasz & Yap, 2013).[1] While these two measures may appear superficially similar, they differ in one key respect: perceptual strength asks people to rate five separate modalities in turn (from which the dominant modality can then be extracted), whereas SER asks people to provide a single rating that is intended to span all five modalities. This difference, between modality-specific versus overall consideration of perceptual experience when evaluating a simulation for extent of perceptual information, is the focus of the following studies.

In the present paper, we investigated whether people can ever be consciously aware of the full content of their perceptual simulations, or whether the act of conscious inspection means that some information will inevitably be lost. The perceptual simulation that comprises the meaning of a word, sentence, or longer discourse is unconscious and automatic: perceptual information is implicitly retrieved but is not necessarily at a level of activation that is available to conscious awareness. However, deliberately inspecting some element of this simulation—such as when evaluating the extent of its perceptual content—involves consciously attending to it and devoting working memory resources to its inspection. As such, conscious imagery of a concept places more demands on working memory than does unconscious simulation of the same concept. In three studies, we examined whether the transfer of perceptual information from unconscious simulation to conscious imagery involves the loss of some of this information. In Study 1, we tested whether bringing a perceptual simulation to conscious awareness involves information loss by comparing two measures of a concept's perceptual content—perceptual strength ratings (for which participants attempted to generate conscious imagery for a single modality of perceptual information at a time) and sensory experience ratings (for which participants attempted to generate conscious imagery for all of a concept's perceptual information at once). In Study 2, we examined whether information loss could be explained by people prioritizing the most dominant perceptual modalities in a particular simulation when generating conscious imagery. Finally, in Study 3, we investigated whether the observed information loss in Studies 1 and 2 really resulted from the transfer of perceptual information from unconscious to conscious awareness by testing which variable—perceptual strength or SER—best predicts performance in lexical decision, a task in which semantic access is automatic and implicit.

Study 1: Separate Perceptual Modalities

We aimed to establish in this first study whether the transfer from unconscious perceptual simulation to conscious imagery in working memory involves information loss (i.e., neglect or distortion of perceptual information). Perceptual simulations do not have to be detailed representations; they can be as sketchy or incomplete as will satisfice current goals (Barsalou, 1999; Louwerse & Connell, 2011). However, when a task involves processing a single word, the unconscious perceptual simulation of its meaning is relatively rich in detail (Connell & Lynott, 2015), and includes perceptual information across multiple modalities (Connell & Lynott, 2014a), affective information of positive/negative valence (Kuperman, Estes, Brysbaert, & Warriner, 2014), and motor information about object interactions (Siakaluk, Pexman, Aguilera, Owen, & Sears, 2008). Moreover, since no concept is truly aperceptual (i.e., completely devoid of perceptual experience: Connell & Lynott, 2012), grounded simulations are critical to representing both concrete and abstract concepts (Barsalou & Wiemer-Hastings, 2005; Vigliocco et al., 2009). If the limited capacity of working memory means that information loss is inevitable when asked to evaluate a potentially large and complex perceptual simulation, then people will be unable to provide a single rating that accurately reflects the full range of multimodal sensory experience involved in a perceptual simulation, unless attention is explicitly drawn to each modality individually. That is, perceptual strength and SER will diverge, with people neglecting information from some or all modalities (i.e., no relationship between particular modality-specific ratings of perceptual strength and SER),

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[1] Although SER is a significant predictor in a model that already includes imageability, SER cannot be said to subsume imageability because the reverse was not tested (i.e., whether imageability is still a meaningful predictor in a model that already includes SER). Perceptual strength subsumes imageability because both orders of variable entry were tested by Connell and Lynott (2012), who showed not only that perceptual strength predicts lexical decision and naming variance in the presence of imageability, but that imageability predicts no variance in the presence of perceptual strength.

and/or distorting it (i.e., modality-specific relationships appearing and disappearing from one end of the SER scale to the other). Following Connell and Lynott's (2012) findings regarding imageability, we hypothesized that the auditory, gustatory, and haptic modalities may be most susceptible to such information loss because people find it difficult to generate conscious imagery in these modalities.

On the other hand, if perceptual simulations can be easily transferred to conscious awareness without information loss, then people should be able to rate reliably the extent to which a word evokes a perceptual experience, regardless of the modalities involved. In this instance, perceptual strength and SER would be closely related, with people taking all modalities into account (i.e., positive relationships between SER and perceptual strength ratings for all five modalities of visual, haptic, olfactory, gustatory, and auditory strength), and doing so consistently (i.e., same modality-specific relationships at low and high ends of SER scale). There would be no requirement for all modalities to contribute equally to SER, just for all modalities to contribute positively across the scale.

Method

Materials. A total set of 554 words were collated, representing the intersection between all available norms of perceptual strength (Lynott & Connell, 2009, 2013; plus additional unpublished items) and SER (Juhasz et al., 2011; Juhasz & Yap, 2013). Sample items are given in Table 1 along with ratings for each variable, highlighting where SER and perceptual strength are consistent (i.e., SER and perceptual strength agree on the extent of perceptual information in a concept) or inconsistent (i.e., SER and perceptual strength disagree on whether a concept has a high or low extent of perceptual information).

Design and analysis. There were two phases of analysis. First, we ran linear regression analysis across the full scale, with SER as the dependent variable and perceptual strength for five modalities (auditory, gustatory, haptic, olfactory, visual) as independent predictors. Table 2 shows zero-order correlations. Second, in order to examine the consistency of the relationship between SER and individual modalities, we split the SER scale at the sample median[2] (2.91) and reran the regression analyses separately for low-SER (n = 276) and high-SER (n = 278) items. We report effect sizes throughout as partial correlations per predictor, with 95% confidence intervals bootstrapped over 1,000 samples from a pseudorandom seed. See online supplementary materials for detailed statistics of zero-order correlations and model coefficients.

Table 1
Sample Words From Studies 1 and 2 With Ratings of Sensory Experience (SER) and Modality-Specific Perceptual Strength

Word	SER	Auditory	Gustatory	Haptic	Olfactory	Visual
		Perceptual strength				
Consistent SER and perceptual strength						
factor	1.91	1.31	0.37	0.31	0.06	**1.87**
breath	3.70	2.18	2.18	1.71	**3.00**	1.71
sword	4.18	1.23	0.00	2.71	0.00	**3.84**
baby	5.40	4.24	0.82	3.65	3.12	**4.88**
music	6.00	**4.94**	0.00	1.24	0.06	2.24
Inconsistent SER and perceptual strength						
pat	1.64	2.12	0.12	**4.29**	0.06	3.06
small	1.80	0.43	0.00	3.67	0.00	**4.95**
rhyme	2.00	**4.68**	0.03	0.00	1.84	0.65
bland	3.00	0.81	**4.81**	0.43	3.62	2.10
heaven	4.00	**1.76**	0.59	0.88	0.82	1.53

Note. Maximum perceptual strength in the dominant modality is shown in bold. SER ranges from 1–7, perceptual strength ratings from 0–5.

Table 2
Zero-Order Correlations, With Means and Standard Deviations, for Sensory Experience Ratings (SER) and Modality-Specific Perceptual Strength in Study 1 (N = 554)

Rating	SER	Auditory	Gustatory	Haptic	Olfactory	Visual
SER	—					
Auditory	−.023	—				
Gustatory	.235	−.103	—			
Haptic	.155	−.276	.180	—		
Olfactory	.316	−.005	.691	.212	—	
Visual	.205	−.243	−.049	.421	.147	—
M	3.03	1.76	0.59	2.05	0.76	3.60
SD	0.99	1.23	1.00	1.31	0.94	0.87

Note. SER ranges from 1–7, perceptual strength ratings from 0–5.

Results and Discussion

Analysis of the full scale showed that perceptual strength in five modalities accounted for a relatively small amount of the variance in SER: R^2 = .131, adjusted R^2 = .123, $F(5, 548) = 16.45$, $p <$ .0001. Such a level of fit is relatively poor for two semantic norms that are ostensibly measuring the same thing (i.e., perceptual experience underlying a conceptual representation) and points toward a distinct difference in the information being rated. Examining the individual contribution of each modality confirmed that the perceptual experience rated in SER diverged from that rated in modality-specific perceptual strength (see Table 3): only visual

Table 3
Standardized Coefficients and Partial Correlations With Associated 95% Confidence Intervals for Each Modality of Perceptual Strength as a Predictor of Sensory Experience Ratings (SER) in Study 1

Modality	β	Partial-*r*	95% CI (partial-*r*)	*t*(548)	*p*
Auditory	.04	.037	[−.060, .134]	0.88	.381
Gustatory	.09	.064	[−.029, .145]	1.50	.134
Haptic	.03	.027	[−.063, .123]	0.63	.527
Olfactory	.22	.164	[.078, .254]	3.89	<.001
Visual	.17	.158	[.060, .256]	3.75	<.001

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[2] We chose to split the scale at its median (2.91) rather than its midpoint (4.00) because a midpoint split would have led to very unequal sample sizes in the low-SER (n = 448) and high-SER (n = 106) subsamples, meaning the relative power of the predictors could not have been fairly compared. Moreover, in the full set of available SER norms (n = 5857: Juhasz & Yap, 2013), both the median (2.82) and modal response (3.00) are also below the scale midpoint, which suggests that our choice of scale partition is close to the central tendency of the SER distribution.

and olfactory experience contributed to SER fit, whereas auditory, gustatory, and haptic experience had no relationship with SER. Collinearity was not a problem: all VIFs < 2.2. This pattern is similar to that reported by Connell and Lynott (2012) for imageability ratings, where auditory, gustatory, and haptic strength failed to contribute to the ease of generating imagery, which overall suggests that perceptual information from these modalities is difficult to examine unless attention is explicitly drawn to them individually.

Analysis of the split scale also produced inconsistencies between low and high SER in terms of their modality-specific relationships. Low SER was not reliably related to perceptual strength, $R^2 = .033$, adjusted $R^2 = .015$, $F(5, 270) = 1.83$, $p = .107$, with no modality acting as a significant predictor (all ps > 0.1, see Figure 1 for partial correlations). High SER was better predicted by modality-specific perceptual strength, $R^2 = .077$, adjusted $R^2 = .060$, $F(5, 272) = 4.53$, $p = .001$, but only olfactory strength contributed reliably, partial $r = .195$, $\beta = 0.269$, $t(272) = 3.27$, $p = .001$ (all other modality ps $> .2$, see Figure 1). As such, it appears that olfactory experience is subject to some distortion when a perceptual simulation is transferred to conscious awareness, with increasing olfactory strength having different effects at low and high ends of the SER scale. Furthermore, the absence of visual strength as a predictor of either low or high SER, when it was present as a predictor of the full scale, is notable. If one examines the visual strength ratings of sample words in Table 1, it is clear that many items with low SER can be strongly visual; indeed, the mean visual strength for low-SER items (visual $M = 3.42$ out of 5) is high, albeit slightly lower than for high-SER items (visual $M = 3.78$). This small but meaningful difference in visual strength between low- and high-SER words allowed it to emerge as an overall predictor across the full scale, but the relationship was insufficiently consistent when examining low and high SER separately.

In summary, it appears that some information is lost when a perceptual simulation transfers to conscious imagery. In line with predictions, auditory, gustatory, and haptic modalities are neglected when people attempt to inspect the perceptual content of a word's referent concept. For instance, strongly perceptual words such as *rhyme* (auditory strength 4.68 out of 5), *mild* (gustatory strength 3.62), and *pat* (haptic strength 4.29) all received quite a low SER (less than 2 out of 7), suggesting that these perceptual aspects of the simulation were not evident to participants when they attempted to rate the sensory experience evoked by each word. That is, low SER does not necessarily mean low in perceptual content.

Moreover, information from the modalities that did contribute to SER—visual and olfactory—is subject to distortion. Visual experience was interpreted inconsistently, as evinced by the mean high visual strength at both ends of the scale. Both *bead* and *cliff* are strongly visual (strength 4.13 and 4.23, respectively), for instance, but only *cliff* evoked a noticeably sensory experience and hence received a high SER (5.00, compared to 1.45 for *bead*). Increasing visual strength does not increase SER by very much at the low end of the scale (i.e., relatively shallow slope, standardized $\beta = 0.098$), and by even less at the high end of the scale (i.e., almost flat slope, standardized $\beta = 0.019$). The differing visual slopes for high and low SER reflect inconsistencies in the pattern of information loss:

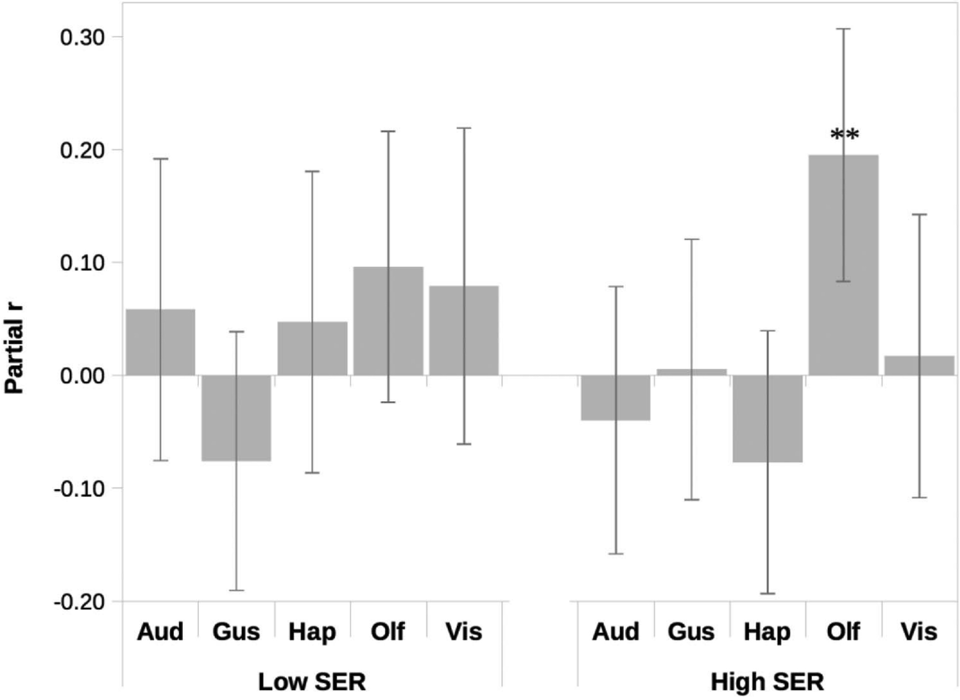

Figure 1. Partial correlations for (Aud)itory, (Gus)tatory, (Hap)tic, (Olf)actory, and (Vis)ual modalities of perceptual strength, with 95% CI, as predictors of sensory experience ratings (SER) at the high-SER and low-SER ends of the scale (Study 1). ** $p < .01$.

high-SER items are more likely to lose visual information than low-SER items. Nonetheless, mean visual strength was slightly higher for high-SER items than low-SER items (see above). Hence, there is a strong enough trend across the full SER scale for increasing visual strength to reliably predict an increase in SER, but it is not robust enough to emerge at separate ends of the scale. There is also inconsistency from one end to another of the SER scale regarding the olfactory modality, where the relationship was present for high SER but not for low SER. A rise in olfactory strength does not necessarily increase SER while sensory experience is considered relatively weak, but the same rise in olfactory strength does increase SER at the relatively strong end of the scale. For example, *lush, damp*, and *waste* steadily increase in olfactory strength (3.00, 3.14, 3.53, respectively), but their SER is weak and undifferentiated (2.55, 2.50, 2.50). In contrast, *grass*, *body*, and *dirty* also have increasing olfactory strength (3.06, 3.35, 3.52), but this time their SER is strong and follows the same increasing trend (4.08, 4.30, 5.09). We believe that these distortions likely result from the relative salience and strength of individual modalities during perceptual experience. At the low end of the SER scale, olfactory strength correlates more closely with other perceptual modalities than it does at the high end of the SER scale.[3] Since olfactory strength is rarely the dominant modality in a concept (Lynott & Connell, 2013), it is more likely to be distorted by stronger, more salient modalities with which it shares variance than to act as a distorter in its own right. Hence, even when collinearity is low, intermodality overlap in perceptual experience weakens the ability of olfactory strength to contribute independently to SER at the low end of the scale, while it retains sufficient independent variance to act as a predictor of SER at the high end of the scale.

These findings suggest that people are unable to provide a single rating that accurately reflects the full range of sensory experience involved in a perceptual simulation; that is, transferring a representation from unconscious simulation to conscious imagery causes some aspects—particularly sound, taste, and touch—to be neglected or distorted. People are not aware of everything they are simulating because bringing it to awareness involves systematic loss of information.

Study 2: Dominance-Ordered Modalities

Study 1 shows that people neglect or distort information from particular modalities when attempting to inspect a perceptual simulation in order to produce an overall rating of sensory experience. However, it is possible that the relatively poor match between modality-specific perceptual strength and SER emerges because people prioritize the strongest (i.e., most dominant) modalities in each simulation when they are asked to inspect perceptual content. That is, people may be able to use a loss-minimizing modality dominance strategy whereby they attend to the strongest, most dominant modality in a perceptual simulation quite easily, and then attend to the second-strongest modality, and so on, but will stop when any modality is too weak to be worth considering. Since most concepts are very weak in at least one modality (Lynott & Connell, 2009, 2013; see Table 1 for examples), inspection of a simulation would therefore usually cease before all five modalities had been taken into account. Such a strategy would effectively result in minimal information loss, but could produce the impression that certain modalities (i.e., auditory, gustatory, haptic) are habitually neglected if they frequently feature in the weakest, least-dominant positions. In the present study, we examine this possibility.

Rather than examine perceptual strength across five individual modalities, we rank-ordered the ratings for each word from maximum perceptual strength (i.e., the most dominant modality) to minimum perceptual strength (i.e., the least dominant modality), and compared these dominance-ordered perceptual strength ratings to SER. If the above possibility is correct, and perceptual simulations can be easily transferred to conscious imagery without (much) information loss by prioritizing dominant information, then people should be able to rate the extent to which a word evokes a perceptual experience in its most dominant modalities. That is, dominance-ordered perceptual strength and SER would be closely related, with the importance of each relationship to SER decreasing systematically from most to least dominant modality (i.e., the strongest positive relationship between SER and maximum perceptual strength, followed by second-to-maximum perceptual strength, etc.), and doing so consistently (i.e., same order of relationships at low and high ends of SER scale).

However, if people are not using such a modality dominance strategy, and perceptual information is inevitably lost when transferred to conscious imagery, then the information loss we observed in Study 1 will reappear in the present study. In this case, dominance-ordered perceptual strength and SER will diverge, with no systematic order of importance from most- to least-dominant modality in terms of their relationship to SER. People will still neglect perceptual information (i.e., no positive relationship between highly dominant modalities and SER), and/or distort it (i.e., relationships appearing and disappearing from one end of the SER scale to the other), regardless of its dominance in the referent concept's simulation.

Method

Our methodology was the same as Study 1, with the exception that perceptual strength ratings were rank-ordered from maximum (first-most dominant) to minimum (fifth-most dominant) on a per-item basis. For example, the modality-specific profile of *scarf* (auditory 0.29, gustatory 0.00, haptic 4.26, olfactory 0.65, visual 4.48) was transformed to the dominance-ordered profile of first-dominant 4.48, second-dominant 4.26, third-dominant 0.65, fourth-dominant 0.29, fifth-dominant 0.00.

Independent predictors were therefore five variables of dominance-ordered perceptual strength ratings (first-dominant, second-dominant, third-dominant, fourth-dominant, fifth-dominant). Table 4 shows zero-order correlations.

Results and Discussion

Analysis of the full SER scale showed that dominance-ordered perceptual strength accounted for a moderately low proportion of variance in SER (R^2 = .219, adjusted R^2 = .212, $F(5, 548)$ = 30.80, $p < .0001$). This level of shared variance (22%) is more than that produced by modality-specific perceptual strength in

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[3] See zero-order correlations in online supplementary materials

Study 1 (13%), which suggests that people are more likely to rely on dominant perceptual information when evaluating sensory experience than move through each modality systematically. However, as in Study 1, examining the contribution of each predictor showed that dominance-ordered perceptual strength diverged from SER in both the order of importance[4] (i.e., not ordered from most to least dominant modality) and direction of relationship (see Table 5). The most dominant modality was most strongly related to SER, but, contrary to a modality dominance strategy, the second most important predictor was actually the fourth-dominant modality. Next came the least dominant and second-dominant modalities, both of which were negatively related to SER instead of the expected positive relationship. Lastly came the third-dominant modality, which was positive but only marginally significant. Collinearity was higher than in Study 1, but not high enough to be a problem: all VIFs < 3.9. Overall, perceptual information shows no systematic order of importance from most to least dominant modality in how it contributes to SER, meaning that some information—not related to its dominance in a particular simulation—is being lost.

Analysis of the median-split SER scale produced inconsistencies between low and high SER in terms of their relationship with dominance-ordered perceptual strength. Low SER was not reliably related to perceptual strength, regardless of dominance: $R^2 = .027$, adjusted $R^2 = .009$, $F(5, 270) = 1.51$, $p = .187$. As shown in Figure 2, none of the predictors, not even the most dominant modality, reliably predicted low SER (all $ps > .14$). High SER was better fit by dominance-ordered perceptual strength ($R^2 = .098$, adjusted $R^2 = .081$, $F(5, 272) = 5.90$, $p < .0001$) but, as for the full scale, some predictors produced negative and null relationships. Specifically (see Figure 2), only the most dominant modality contributed positively to SER (partial $r = .234$, $\beta = 0.234$, $t(272) = 3.96$, $p < .0001$), second-dominant strength again had a negative effect (partial $r = -.162$, $\beta = -0.191$, $t(272) = -2.71$, $p = .007$), third-dominant was marginally positive (partial $r = .102$, $\beta = 0.168$, $t(272) = 1.69$, $p = .092$), and the remaining variables did not contribute significantly ($ps > .27$). It therefore appears that, as found for modality-specific perceptual information in Study 1, dominance-ordered perceptual information is subject to distortion when brought to conscious awareness, with even the most dominant modalities in a concept's representation having different effects at the low and high ends of the SER scale.

Table 4
Zero-Order Correlations With Means and Standard Deviations for Sensory Experience Ratings (SER) and Dominance-Ordered Modalities of Perceptual Strength From Most Dominant (1st) to Least Dominant (5th) in Study 2 (N = 554)

Rating	SER	1st	2nd	3rd	4th	5th
SER	—					
1st dominant	.419	—				
2nd dominant	.176	.390	—			
3rd dominant	.222	.163	.505	—		
4th dominant	.231	.172	.412	.750	—	
5th dominant	.076	.030	.251	.557	.763	—
M	3.03	3.85	2.63	1.31	0.65	0.32
SD	0.99	0.76	1.00	0.88	0.70	0.45

Note. SER ranges from 1–7, perceptual strength ratings from 0–5.

Table 5
Standardized Coefficients and Partial Correlations With Associated 95% Confidence Intervals for Each Dominance-Ordered Modality of Perceptual Strength as a Predictor of Sensory Experience Ratings (SER) in Study 2

Dominance-ordered modality	β	Partial *r*	95% CI (partial-*r*)	*t*(548)	*p*
Most dominant	.40	.383	[.310, .457]	9.71	<.001
Second-dominant	−.10	−.088	[−.179, −.002]	−2.06	.040
Third-dominant	.12	.082	[−.016, .172]	1.93	.054
Fourth-dominant	.23	.132	[.040, .218]	3.11	.002
Least dominant	−.15	−.110	[−.196, −.026]	−2.60	.010

In summary, people seem to rely in part on the strongest, most dominant modality when transferring a simulation to conscious imagery in working memory, but do not consistently employ a modality dominance strategy. Some modalities had a null relationship with SER rather than the positive one that would be expected if people were accurately evaluating perceptual imagery: only the strongest and fourth-strongest modalities actually increased SER. Moreover, the second-strongest and weakest modalities are arguably misinterpreted, rather than simply neglected, by having a negative relationship with SER. In order to explore this issue further, we conducted a stepwise regression of the full SER scale, in which we entered each dominance-ordered modality in turn in separate steps, and observed when negative relationships first appeared. Results (see online supplementary materials) showed that the second-dominant modality was a nonsignificant predictor when first entered in the model alongside the most-dominant modality, and then became an increasingly stronger suppressor (i.e., negative coefficient) as the third-dominant and subsequent modalities were entered. This pattern of results suggests that simultaneously considering two modalities leads to information being neglected, but simultaneously considering three or more modalities leads to outright distortion of information. For multimodal concepts, information from the second most dominant modality is not only lost, but detrimentally affects people's ability to reliably gauge the extent of perceptual experience in the strongest, most dominant modality. Based on these findings, we speculate that increasing the number of strong modalities in a concept increases the difficulty of transferring perceptual information from unconscious simulation to conscious awareness in the SER rating task. Negative relationships—namely those for the second-dominant (and fifth-dominant) modalities—are effectively an index of the difficulty of selecting a salient subset of perceptual

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[4] We chose to order the relative importance of predictors by effect size (partial-*r*) rather than by standardized coefficients because the second-dominant and least-dominant modalities have negative coefficients despite their positive zero-order correlations. As such, they act to enhance the effect of the other modalities by suppressing their unhelpful error variance (Cohen, Cohen, West, & Aiken, 2003), and so their standardized coefficients reflect their moderation of other modalities more so than their direct contribution to SER. In contrast, partial-*r* reflects how much each predictor contributes to SER when the effects of the other modalities have been removed from both the predictor in question and SER itself, which is more useful to our present purposes.

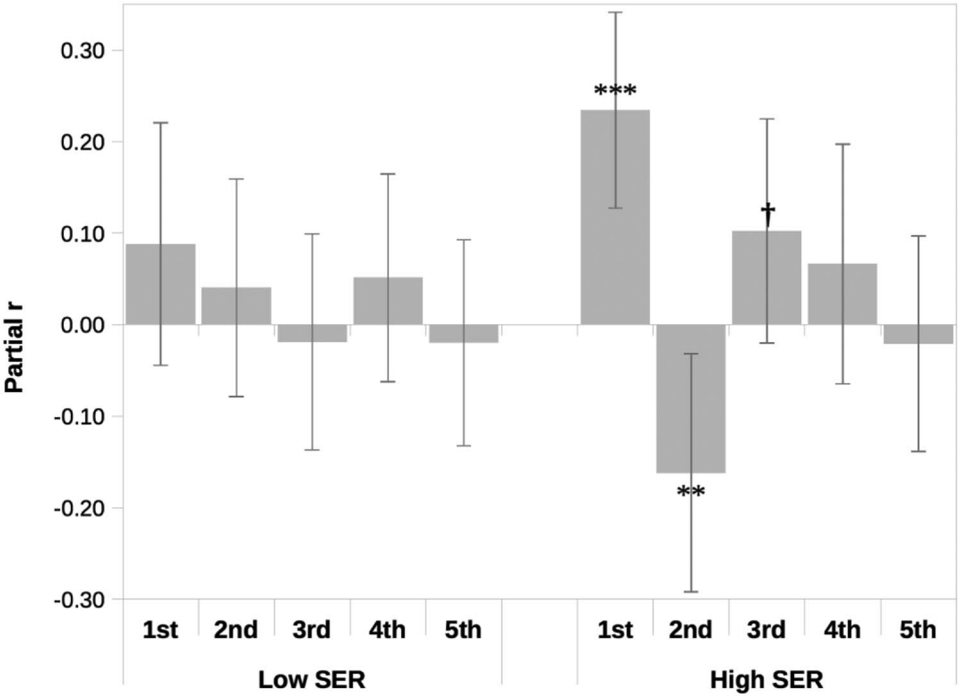

Figure 2. Partial correlations for dominance-ordered modalities of perceptual strength from most dominant (1st) to least dominant (5th), with 95% CI, as predictors of sensory experience ratings (SER) at the high-SER and low-SER ends of the scale (Study 2). † $p < .10$. ** $p < .01$. *** $p < .001$.

information to fit in working memory. Unimodal concepts can be consciously evaluated with relatively little information loss because a single dominant modality places the least strain on working memory. Bimodal concepts suffer information neglect because the presence of a second strong modality strains working memory and leads to it being ignored in favor of the dominant modality. Finally, multimodal concepts suffer information distortion because the presence of three or more strong modalities places a significant strain on working memory and leads to confusion because people can neither successfully ignore nor incorporate so much perceptual information.

All in all, these findings support the conclusion of Study 1 that people are unable to evaluate the full range of sensory experience unless attention is drawn to each modality individually. That is, people are effectively unaware of what they are simulating, and lose information from their perceptual simulations when attempting conscious inspection. Moreover, it appears that perceptually complex concepts, where two or more modalities are strongly dominant in a simulation, are more difficult to examine and more prone to information loss than perceptually simple concepts where a single modality dominates.

Study 3: Lexical Decision

Although Studies 1 and 2 showed that people systematically lose information from various modalities when attempting to evaluate sensory experience as a whole, how can we be sure that this information loss is the result of bringing an unconscious perceptual simulation to conscious awareness? It could be argued that people generate and manipulate a qualitatively different type of conceptual representation when asked to provide a rating compared to when implicitly accessing meaning during typical language processing. That is, even though our earlier studies were based on the assumption that perceptual imagery is a conscious subset of unconscious perceptual simulation (Barsalou, 2009; Moulton & Kosslyn, 2009), perhaps this assumption was incorrect and these two types of perceptual representation are very different in content and process. In such a case, both perceptual strength and SER would suffer from the same problem, because neither type of semantic variable would be capable of tapping into the unconscious perceptual simulation that is automatically accessed as word meaning, and instead would reflect a different form of perceptual imagery that was specifically and deliberately created for the rating task. In this final study, we aimed to compare the ability of the variables examined in Studies 1–2 to predict lexical decision performance, a task whose semantic effects emerge from automatic access to the full potential of unconscious perceptual simulation (Connell & Lynott, 2014a, 2015; Juhasz et al., 2011).

Deciding whether or not a letter string constitutes a valid word is facilitated by the perceptual semantics of the referent concept: that is, strongly perceptual words are recognized more quickly than weakly perceptual words (Connell & Lynott, 2012, 2014a, 2015; Juhasz et al., 2011; Juhasz & Yap, 2013; see also Paivio, 1986). If the perceptual content rated during conscious imagery is different from the perceptual content accessed during unconscious simulation of meaning, then both perceptual strength and SER would account for approximately equal variance in lexical decision performance because they each represent a qualitatively different construct from the unconscious perceptual simulation that underlies semantic effects in word recognition. In other words, both ratings scales would predict useful, but incomplete semantic effects because they both capture a useful but imperfect overlap of the possible sensory information in an unconscious perceptual simulation.

But if our earlier assumption was correct, and the information loss we found in Studies 1 and 2 occurred because of difficulties in bringing a multimodal perceptual simulation to conscious imagery, then this information loss will carry over into the present study in the form of differential effects for SER and perceptual strength. In this case, perceptual strength will outperform SER in explaining semantic effects in lexical decision because it represents a "truer" (i.e., less prone to neglect and distortion) transfer of perceptual information from unconscious to conscious awareness. That is, both ratings scales would tap into a qualitatively identical perceptual simulation to that which is automatically accessed during word processing, but SER loses some of this information (i.e., particularly from auditory, gustatory, and haptic modalities) in a way that perceptual strength does not, and hence is less able than perceptual strength to predict semantic effects in lexical decision.

Method

Materials. Since SER norms were collected from speakers of American English, and perceptual strength norms from speakers of British English, we utilized lexical decision data from both American and British English speakers so as not to offer one rating method an unfair predictive advantage. To that end, lexical decision response times (RT), standardized response times with individual variance removed (zRT), and accuracy (Acc), were taken for American English from the English Lexicon Project (Elexicon: Balota et al., 2007) and for British English from the British Lexicon Project (BLP: Keuleers, Lacey, Rastle, & Brysbaert, 2012). Of the materials used in Studies 1 and 2, 546 words had available data in Elexicon and 521 in the BLP. Elexicon also provided lexical variables to act as predictors, as described below. It should be noted that, while this study draws on publicly available datasets, the analyses—and hypotheses—in this study are new.[5] Table 6 shows zero-order correlations.

Design and analysis. For each dependent variable (RT, zRT, and Acc for each of Elexicon and BLP data), we ran hierarchical linear regression analyses to determine the proportion of variance each candidate rating could explain. Step 1 entered lexical predictors that commonly contribute to lexical decision performance: log SUBTLEXus word frequency, length in letters, orthographic neighborhood size, and phonological neighborhood size. Step 2 entered either SER or maximum perceptual strength (i.e., the highest of the five modality-specific ratings, representing perceptual strength in the concept's dominant modality). We utilized maximum perceptual strength, rather than individual ratings in separate modalities, because it was previously shown to be an effective predictor of lexical decision data (Connell & Lynott, 2012) and because, as a single variable, it offered a fair statistical comparison with SER. Furthermore, it allowed us to conduct the following step in the hierarchical regression without overinflating the number of predictors. Step 3 entered the interaction between log word frequency and the rating entered in the previous step (i.e., SER or maximum perceptual strength), which was calculated using centered values for each variable. Since semantic effects are typically stronger for low-frequency words than high-frequency words (e.g., James, 1975; Kroll & Merves, 1986), entering the interaction term allows a full picture to emerge of how much variance in lexical decision performance can be explained by each candidate rating, which has not been examined in previous studies. Confidence intervals (95%) for partial correlations were bootstrapped over 1,000 samples from a pseudorandom seed.

Finally, for each of the six regression models, we compared the relative predictive ability of SER versus maximum perceptual strength in an Hotelling-Williams test (Steiger, 1980) on the total improvement in fit between Step 1 and Step 3, using Holm's (1979) Bonferroni corrections for multiple comparisons; that is, we tested whether SER (plus its interaction with frequency) accounted for a significantly different proportion of variance than maximum perceptual strength (plus its interaction with frequency).[6] In addition, we compared the fit of the data under SER and maximum perceptual strength by estimating Bayes Factor based on the Bayesian Information Criterion (BIC) for each of the SER and perceptual strength models at Step 3 (Kass & Raftery, 1995; Wagenmakers, 2007).

Results and Discussion

Table 7 reports the change in fit at each step of each regression model and Table 8 contains the partial correlations and coefficients of the semantic predictors (see online supplementary materials for additional statistics). Both SER and maximum perceptual strength facilitated lexical decision latency and accuracy in Elexicon and BLP samples (although SER was not a reliable predictor of BLP latency). However, the variables did not interact with frequency to the same extent. Perceptual strength affected low-frequency words more than high-frequency words for both latency and accuracy. SER had this effect for accuracy alone. Collinearity for predictors and their interaction terms was low (VIFs < 1.3).

Critically, when examining relative predictive ability, the total semantic effect of perceptual strength (1.7–5.2% variance) consistently accounted for more variance in lexical decision performance than did that of SER (0.2–3.7% variance: see Figure 3). In the Elexicon dataset, perceptual strength (and its frequency interaction) increased model fit more than did SER (and its frequency interaction) in RT, $t(543) = 2.50$, $p = .025$; zRT, $t(543) = 7.34$, $p < .001$; and Acc, $t(543) = 2.00$, $p = .046$. The same pattern appeared in the BLP dataset for RT, $t(518) = 13.02$, $p < .001$; zRT, $t(518) = 12.69$, $p < .001$; and Acc, $t(518) = 4.19$, $p < .001$.

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[5] Connell and Lynott (2012, 2014a) previously showed that perceptual strength predicts lexical decision times and accuracy from Elexicon, but for a different set of items that only partly overlap with the current set; perceptual strength has not previously been examined with BLP data, nor compared to SER. Similarly, SER has been used to predict lexical decision times from Elexicon (Juhasz & Yap, 2013), and lexical decision time and accuracy from the BLP (Juhasz, Yap, Dicke, Taylor, & Gullick, 2011), but these analyses were for different (partially overlapping) set of items; SER has not been examined with lexical decision accuracy from Elexicon, nor has performance been contrasted with perceptual strength.

[6] Since multiple regression is essentially a Pearson correlation between obtained and predicted dependent variables, the Hotelling-Williams test can be used to compare two regression models that share a dependent variable (i.e., non-nested model comparison) by including the correlation between the predicted values of each model (Tabachnick & Fidell, 2007).

Table 6

Zero-Order Correlations for Variables in Study 3's Regressions of Lexical Decision Response Times (RT), Standardized Response Times (zRT), and Accuracy (Acc) From Elexicon (n = 546) and British Lexicon Project (BLP: n = 521)

Rating	1	2	3	4	5	6	7	8
1. Log word frequency	—							
2. Length in letters	−.150	—						
3. Orthographic neighbors	.195	−.706	—					
4. Phonological neighbors	.164	−.630	.727	—				
5. SER	.021	.173	−.186	−.182	—			
6. SER × Log word frequency	−.105	−.024	−.043	.029	−.024	—		
7. Maximum perceptual strength	.101	−.055	.024	−.015	.425	.018	—	
8. Maximum perceptual strength × Log word frequency	−.050	−.004	−.047	.017	.017	.438	.068	—
Elexicon RT	−.583	.237	−.187	−.162	−.094	.019	−.198	.048
Elexicon zRT	−.651	.239	−.212	−.164	−.067	.074	−.184	.101
Elexicon Acc	.475	.032	.043	−.023	.162	−.200	.169	−.215
BLP RT	−.671	.135	−.137	−.048	−.049	.063	−.192	.095
BLP zRT	−.676	.132	−.130	−.036	−.067	.069	−.214	.103
BLP Acc	.461	.116	−.027	−.123	.139	−.127	.136	−.188

Note. Interaction terms were created from centered variables. Interpredictor correlations are for the larger Elexicon dataset; those for the BLP dataset differed little (see online supplementary materials).

Model comparisons using Bayes Factors (BF: see Table 9) confirmed that, in all cases, the data were in favor of maximum perceptual strength over SER. On average, the data were several thousand times more likely (mean $\text{BF} = 4{,}586$) to occur under a model including maximum perceptual strength (and its frequency interaction) than a model including SER (and its frequency interaction). To put these values in context, any $\text{BF} > 150$ is typically interpreted as constituting very strong evidence (Kass & Raftery, 1995; Wagenmakers, 2007).

Nonetheless, it could be argued that the above non-nested model comparisons are concerned with a relatively small difference in predictive ability, and that a more conservative test would be to examine whether maximum perceptual strength can explain variance in lexical decision performance over and above SER.[7] We therefore subjected the SER models to two additional hierarchical steps: Step 4 entered maximum perceptual strength, whereas Step 5 entered the interaction between log word frequency and maximum perceptual strength. We then examined whether there was a significant increase in R^2 between Step 3 (i.e., the SER model) and Step 5 (i.e., the model with maximum perceptual strength in addition to SER). Results (see Tables 7 and 10) showed that perceptual strength explained 1.2–2.7% unique variance above and beyond SER in all models. Collinearity among semantic predictors was again low (VIFs <1.3). That is, even when SER has already been taken into account, maximum perceptual strength still predicts lexical decision performance, which is consistent with the idea that perceptual strength contains useful information that has been lost to SER.

Results show that semantic effects in lexical decision, a task in which semantic access is automatic and unconscious, are better predicted by the maximum modality-specific rating of perceptual strength than the overall rating of SER. Specifically, perceptual strength explains an average of 2.6% of lexical decision variance, more than twice what SER explains at 1.2%. Although such values may seem numerically small, the 2.6% effect size of perceptual strength (and, indeed, the 1.4% advantage of perceptual strength over SER) is larger than that of many other theoretically important semantic variables on lexical decision, such as that of imageability (0.3–2.5%: Connell & Lynott, 2012; Pexman, Hargreaves, Siakaluk, Bodner, & Pope, 2008), number of semantic features (1.3%: Pexman et al., 2008), or affective valence and arousal (2.0% and 0.1%, respectively: Kuperman et al., 2014). In other words, the differences in informational content between perceptual strength and SER that we observed in Studies 1 and 2 have a direct behavioral consequence. Our findings suggest that conscious imagery during a rating task and unconscious semantic access during word processing are both accessing the same perceptual information, rather than imagery requiring the construction of a qualitatively different conceptual representation. SER involved the loss of some perceptual information relative to perceptual strength, and hence SER can explain less variance in lexical decision performance. Because perceptual strength requires attending to each modality individually, it represents a somewhat more complete or accurate transfer of perceptual information from unconscious to conscious awareness, and therefore does better in predicting lexical decision performance. As such, the present study supports our earlier conclusions from Studies 1 and 2: people cannot reliably move perceptual information from unconscious to conscious awareness because inspecting a simulation tends to involve information loss.

General Discussion

We investigated whether it is possible to be aware of what one is mentally representing; that is, whether it is possible to consciously examine the contents of a perceptual simulation without losing information. Results of Study 1 showed that people are unable to reliably rate the true extent to which a concept is based on sensory experience (i.e., the perceptual content of a simulation), and neglect and distort some aspects of their simulation unless their attention is explicitly drawn to them. Specifically, when comparing ratings of perceptual strength in five separate modalities with an overall rating of sensory experience (SER), we found that SER was unrelated to auditory, gustatory, and haptic experi-

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[7] We thank an anonymous reviewer for suggesting this analysis.

Table 7

Changes in Model Fit for Each Step of Study 3's Hierarchical Regressions of Lexical Decision Response Times (RT), Standardized Response Times (zRT), and Accuracy (Acc), From Elexicon and British Lexicon Project (BLP)

	Elexicon			BLP		
Predictor	RT	zRT	Acc	RT	zRT	Acc
R^2 Step 1 (basic model)	**.365*****	**.446*****	**.243*****	**.463*****	**.472*****	**.262*****
Perceptual strength model						
ΔR^2 Step 2 (Perceptual strength)	.017***	.012**	.015***	.015***	.020***	.009*
ΔR^2 Step 3 (Perceptual strength × Frequency)	.001	.006*	.038***	.002	.003†	.021***
R^2 Step 3 (total effect model)	**.383*****	**.464*****	**.295*****	**.480*****	**.495*****	**.292*****
SER model						
ΔR^2 Step 2 (SER)	.011**	.006*	.018***	.001	.003†	.009*
ΔR^2 Step 3 (SER × Frequency)	.001	.000	.019***	.000	.000	.005†
R^2 Step 3 (total effect model)	**.377*****	**.452*****	**.280*****	**.465*****	**.475*****	**.276*****
ΔR^2 Step 4 (Perceptual strength)	.009**	.007**	.006*	.014***	.018***	.004
ΔR^2 Step 5 (Perceptual strength × Frequency)	.003	.006*	.021***	.002	.003	.016**
R^2 Step 5 (unique effect model)	**.389*****	**.466*****	**.307*****	**.481*****	**.495*****	**.295*****

Note. Overall model fit per step is shown in bold.
† $p < .10$. * $p < .05$. ** $p < .01$. *** $p < .001$.

ence, and inconsistently related to olfactory and visual experience, meaning that information from these modalities is lost when deliberately examining a simulation by generating conscious imagery. Additionally, when we ordered the modality ratings for each word by dominance, we found in Study 2 that the most dominant modality was most strongly related to SER, but the second-dominant modality was negatively related, which suggests that information loss is more pervasive for complex, multimodal simulations. Finally, in Study 3, we investigated whether such information loss really resulted from the transfer of perceptual information from unconscious to conscious awareness, rather than from a qualitative difference in the representations created for rating tasks versus unconscious simulation of meaning. Results showed that maximum perceptual strength (i.e., the dominant modality) consistently outperformed SER in accounting for variance in lexical decision performance, a task whose semantic effects emerge from automatic access to the full potential of unconscious perceptual simulation. The information loss observed in Studies 1 and 2 therefore results from the differential ability of perceptual strength and SER to transfer a perceptual simulation to conscious imagery. Together, the present findings suggest that people cannot be aware of everything they are simulating because the act of bringing it to awareness leads to systematic loss of information.

So why does information loss occur? We suggest that the limited capacity of working memory is mainly responsible: because the full representational content of a perceptual simulation is more than can be held in working memory at once, something has to go. In the same way that we cannot attend to all aspects of ongoing perceptual experience, we cannot attend to all aspects of a perceptual simulation. It does not mean that the unattended perceptual experience or simulation is not present, but rather means that we do not devote any working memory resources to its processing, and so it is lost to conscious awareness. Nonetheless, information is not lost arbitrarily. When people attempt to bring simulation content to conscious awareness as imagery, the working memory buffer does not have to hold the entire panoply of perceptual information all in one go. Rather, as the plot of a novel or the gist of a conversation can be represented with only the most relevant aspects active in working memory at any one time (e.g., Ericsson & Kintsch, 1995; Zwaan, 2004), the full perceptual (and motor, affective, etc.) experience underlying word meaning can be unconsciously simulated with only the most relevant subset of information (e.g., a single modality) active in working memory. For SER, all perceptual content must be examined to provide a single rating, which means that the subset of perceptual information that makes it to working memory as conscious imagery tends to skip over information from some modalities (particularly sound, taste, and touch) and distort information from other modalities (particularly sight and smell). For perceptual strength ratings, however, each modality is examined and rated in turn, and so the subset of perceptual information that makes it to working memory can encompass a significant amount of auditory information for the auditory rating, which is then replaced by gustatory information for the gustatory rating, and so on until a relatively broad range of information from each modality has been considered. It is unlikely that all perceptual information from each modality can be represented and inspected in this way, but the results of Study 3 and other related research (Connell & Lynott, 2012, 2014a) suggest that a useful amount of information from each modality does make it through.

The question then arises of what makes information *relevant*. If the most relevant information makes it to working memory when people attempt to inspect a perceptual simulation, what is it about auditory, haptic, and gustatory content that makes it less useful than visual or olfactory content? One possibility is that regularities within multimodal experience can offer a heuristic as to what information can be most safely jettisoned. Previous research has shown that visual and haptic experience tends to correlate, as does olfactory and gustatory experience, while auditory experience stands alone (Louwerse & Connell, 2011; Lynott & Connell, 2009, 2013; van Dantzig, Cowell, Zeelenberg, & Pecher, 2011; see also Table 2). Many aspects of visual experience, such as colors and patterns, have no haptic counterpart, but the reverse is true far less

Table 8

Standardized Coefficients and Partial Correlations With Associated 95% Confidence Intervals for Maximum Perceptual Strength and SER Variables in the Total Effect Model (Step 3) of Study 3's Regressions of Lexical Decision Response Times (RT), Standardized Response Times (zRT), and Accuracy (Acc), From Elexicon and British Lexicon Project (BLP)

	Elexicon			BLP		
Statistic per predictor	RT	zRT	Acc	RT	zRT	Acc
			Perceptual strength model			
β						
Perceptual strength	$-.136^{***}$	$-.118^{***}$	$.136^{***}$	$-.126^{***}$	$-.147^{***}$	$.104^{**}$
Perceptual strength × Frequency	.033	$.079^{*}$	$-.196^{***}$	.046	$.054^{\dagger}$	$-.146^{***}$
Partial r[95% CI]						
Perceptual strength	$-.168^{***}$ [−.254, −.077]	$-.157^{***}$ [−.241, −.069]	$.161^{***}$ [.066, .261]	$-.170^{***}$ [−.251, −.084]	$-.201^{***}$ [−.287, −.118]	$.121^{**}$ [.026, .217]
Perceptual strength × Frequency	−.041 [−.062, .150]	$.106^{*}$ [.002, .218]	$-.225^{***}$ [−.371, −.074]	.063 [−.031, .151]	$.076^{\dagger}$ [−.009, .168]	$-.169^{***}$ [−.298, −.026]
			SER model			
β						
SER	$-.110^{**}$	$-.079^{*}$	$.136^{***}$	−.038	$-.054^{\dagger}$	$.096^{**}$
SER × Frequency	−.036	.009	$-.139^{***}$	.009	.013	$-.069^{\dagger}$
Partial r[95% CI]						
SER	$-.134^{**}$ [−.216, −.057]	$-.104^{*}$ [−.181, −.019]	$.155^{***}$ [.083, .232]	−.051 [−.139, .035]	$-.073^{\dagger}$ [−.164, .016]	$.109^{**}$ [.029, .193]
SER × Frequency	−.045 [−.139, .046]	.012 [−.088, .114]	$-.160^{***}$ [−.270, −.036]	.011 [−.092, .120]	.018 [−.094, .130]	$-.080^{\dagger}$ [−.205, .033]

Note. The larger semantic effect on low-frequency words than high-frequency words results in an interaction variable producing a positive coefficient in regression of response times, and a negative coefficient in regression of accuracy rates.

† $p < .10$. * $p < .05$. ** $p < .01$. *** $p < .001$.

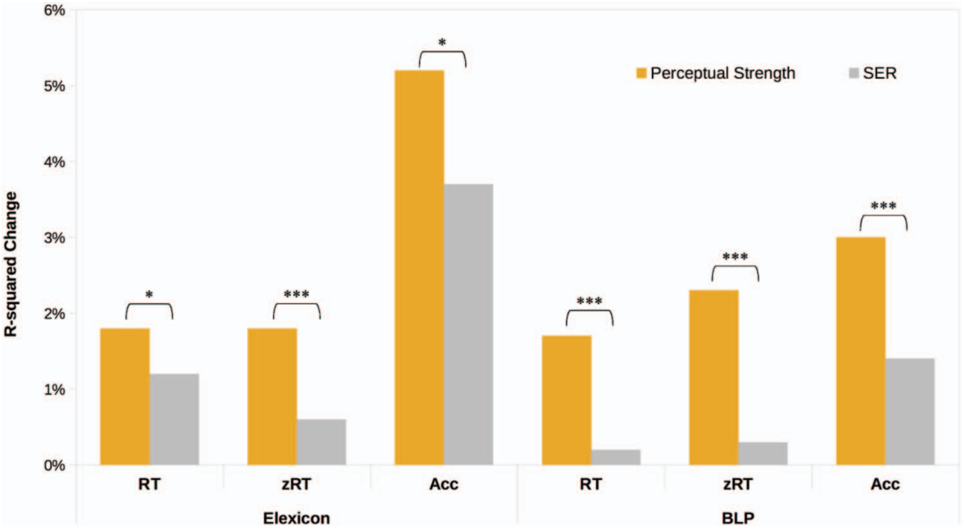

Figure 3. Total proportion of variance explained by sensory experience ratings (SER) and maximum perceptual strength (including their respective interactions with word frequency), over and above a basic model of lexical and sublexical variables, in regressions of lexical decision response time (RT), standardized response time (zRT) and accuracy (Acc), from Elexicon and British Lexicon Project (BLP). $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$ for Hotelling-Williams comparisons with Holm-Bonferroni corrections. See the online article for the color version of this figure.

often (i.e., that which can be touched can usually be seen). In that respect, attending to vision and ignoring touch might be a reasonable heuristic to employ when representational capacity is limited. This idea is consistent with a more general tactile disadvantage found in both perception (Spence, Nicholls, & Driver, 2001; Turatto, Galfano, Bridgeman, & Umiltà, 2004) and conceptual processing (Connell & Lynott, 2010), whereby anticipated touch information is the slowest to detect, and most prone to error, of all the perceptual modalities. Similarly, there are some aspects of olfactory experience that are not tasted, such as perfumes, but gustatory and olfactory modalities are largely engaged together in experience of foods and flavors (i.e., that which can be tasted can usually be smelled). Hence, attending to olfaction and ignoring taste might be a reasonable heuristic to maximize information capture. Auditory experience, however, is different. It is not systematically related to other forms of perceptual experience; indeed, ratings of auditory strength tend to correlate negatively with perceptual strength in other modalities (e.g., Table 2; Lynott & Connell, 2009, 2013; van Dantzig et al., 2011). Strongly auditory concepts also tend to have the highest modality exclusivity (i.e., more likely to be perceived through a single modality: Lynott & Connell, 2009, 2013). That which can be heard is not necessarily perceptible through another modality (e.g., *echo, rhyme*), and that which can be seen, touched, smelled, or tasted often produces no sound (e.g., *steak*, *warm*). It is perhaps this singularity that makes auditory information less useful than the visual/haptic or olfactory/gustatory clusters of perceptual experience, and susceptible to neglect unless attention is specifically drawn to it. The fact that adults tend to discard auditory information in a way that children do not (Sloutsky & Napolitano, 2003) supports the notion of a learned heuristic underlying auditory information loss.

The information loss we observed in the present studies is unlikely to be a unique feature of rating tasks, and we would expect it to generalize to a range of circumstances that require people to inspect or evaluate some aspect of a simulation. The ease of generating perceptual imagery for a word (i.e., imageability) and the extent of perceptual experience evoked by a word (i.e., SER) are moderately well correlated at $r = .586$ (Juhasz & Yap, 2013), suggesting that they reflect related, but different, judgments

Table 9
Bayesian Information Criteria (BIC) for Perceptual Strength and SER Models at Step 3 of Study 3's Hierarchical Regressions of Lexical Decision Response Times (RT), Standardized Response Times (zRT), and Accuracy (Acc), From Elexicon and British Lexicon Project (BLP), Along With Estimated Bayes Factors (BF) in Favor of Perceptual Strength Over SER

	Elexicon			BLP		
Predictor	RT	zRT	Acc	RT	zRT	Acc
BIC perceptual strength	−219.54	−296.38	−146.74	−296.58	−311.83	−135.79
BIC SER	−214.25	−284.29	−135.24	−281.76	−291.59	−124.15
BF (perceptual strength)	14.04	421.80	313.43	1649.26	24779.61	337.47

Table 10

Standardized Coefficients and Partial Correlations With Associated 95% Confidence Intervals for All Semantic Variables in the Unique Effect Model (Step 5) That Entered Maximum Perceptual Strength on Top of SER, in Study 3's Regressions of Lexical Decision Response Times (RT), Standardized Response Times (zRT), and Accuracy (Acc), From Elexicon and British Lexicon Project (BLP)

	Elexicon			BLP		
Statistic per predictor	RT	zRT	Acc	RT	zRT	Acc
β						
SER	−.063	−.036	.098*	.020	.011	.066
SER × Frequency	−.056	−.026	−.072†	−.010	−.008	−.008
Perceptual strength	−.109**	−.102**	.096*	−.134***	−.152***	.075†
Perceptual strength × Frequency	.056	.089*	−.164***	.050	.058	−.142***
Partial *r*[95% CI]						
SER	−.070 [−.149, .006]	−.043 [−.124, .040]	.103* [.028, .177]	.024 [−.059, .104]	.014 [−.067, .093]	.069 [−.006, .148]
SER × Frequency	−.064 [−.158, .022]	−.032 [−.141, .075]	−.076† [−.192, .060]	−.012 [−.114, .086]	−.010 [−.115, .091]	−.008 [−.128, .105]
Perceptual strength	−.123** [−.207, −.032]	−.123** [−.212, −.035]	.102* [.005, .213]	−.164*** [−.240, −.081]	−.188*** [−.271, −.100]	.080† [−.013, .173]
Perceptual strength × Frequency	.064 [−.041, .172]	.109* [.001, .210]	−.173*** [−.321, −.026]	.062 [−.024, .142]	.072 [−.017, .158]	−.148*** [−.280, −.022]

Note. The larger semantic effect on low-frequency words than high-frequency words results in an interaction variable producing a positive coefficient in regression of response times, and a negative coefficient in regression of accuracy rates.

$^{\dagger}p < .10$. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

regarding the perceptual basis of concepts. However, they are subject to the same pattern of information loss (Study 1; Connell & Lynott, 2012), with both tending to neglect and/or distort the auditory, haptic, and gustatory modalities more than vision or olfaction. Hence, it seems that SER and imageability ratings both lose information in the same way when attempting to transfer a conceptual representation from automatic, unconscious simulation to conscious imagery, and differ in the decision processes made on that information (i.e., rating the *extent* of sensory imagery vs. *ease of generating* sensory imagery). It is therefore likely that any process that requires the conscious inspection of conceptual representations (or at least of their perceptual aspects) will be susceptible to the same information loss. It bears further investigation to determine how widespread is the tendency to lose sensory information from sound, touch, and taste in other cognitive tasks such as semantic similarity judgments or autobiographical recall.

An older tradition in cognitive research has viewed semantics and mental representation in terms of the architectures and structures that allowed symbols to be manipulated (e.g., Collins & Quillian, 1969; Pylyshyn, 1984; see Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012, for review). The representational content of those symbols was unimportant to their function, as they were divorced from the sensory and motor systems through which they were originally learned. In the last few years, the consensus has shifted to viewing semantics and mental representation—and cognition more broadly—in terms of the sensory and motor systems that produce emergent structures through simulations of experience (e.g., Barsalou, 1999; Connell & Lynott, 2014b; Glenberg & Robertson, 2000; Vigliocco et al., 2009). Here, the representational content of simulations is essential to their function, as they remain grounded in the sensory and motor systems that host the simulation. Critically, they still permit manipulation in "symbolic" operations (Barsalou, 2008). Our findings in the present paper show that there are systematic patterns in how perceptual information is lost when such simulated content must move to finite-capacity working memory in order to be to be manipulated. Future research should determine how nonperceptual aspects of simulations, such as motor or affective information, may also be subject to loss when conscious inspection is required.

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