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Modality Switching Costs Emerge in Concept Creation as Well as Retrieval

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Abstract

Theories of embodied cognition hold that the conceptual system uses perceptual simulations for the purposes of representation. A strong prediction is that perceptual phenomena should emerge in conceptual processing, and, in support, previous research has shown that switching modalities from one trial to the next incurs a processing cost during conceptual tasks. However, to date, such research has been limited by its reliance on the retrieval of familiar concepts. We therefore examined *concept creation* by asking participants to interpret modality-specific compound phrases (i.e., conceptual combinations). Results show that modality switching costs emerge during the creation of new conceptual entities: People are slower to simulate a novel concept (e.g., auditory *jingling onion*) when their attention has already been engaged by a different modality in simulating a familiar concept (e.g., visual *shiny penny*). Furthermore, these costs cannot be accounted for by linguistic factors alone. Rather, our findings support the embodied view that concept creation, as well as retrieval, requires situated perceptual simulation.

Keywords: Embodied cognition; Perceptual simulation; Modality switching; Representation; Concepts; Conceptual combination

1. Introduction

The conceptual system co-opts the perceptual system for the purposes of representation. This statement is the central tenet of embodied theories of representation that hold conceptual thought to be grounded in the same neural systems that govern sensation, perception, and action (Barsalou, 1999; Barsalou, Santos, Simmons, & Wilson, 2008; Gallese & Lakoff, 2005; Gibbs, 2003, 2006; Glenberg & Kaschak, 2002; Pecher & Zwaan, 2005). Barsalou's

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(1999) Perceptual Symbol Systems theory, for example, describes concepts essentially as partial recordings of the neural activation that arises during perceptual and motor experiences. These recordings (known as perceptual symbols) can later be re-enacted as a perceptual simulation of that concept. Such theories of representation lie in contrast to other, symbolic-computational views of conceptual thought that assume concepts are discrete, amodal representations that are stored in semantic memory, separated from systems governing perception and action (e.g., Collins & Quillian, 1969; Fodor, 1975; Katz & Fodor, 1963; Kintsch & van Dijk, 1978; Newell & Simon, 1972; Pylyshyn, 1984; Tulving, 1972).

A strong prediction of the embodied view, and one that distinguishes it from other theories of mental representation, is that perceptual phenomena should emerge in conceptual processing. If the conceptual system uses perceptual simulations for the purposes of representation, then it follows that one should expect the same factors that facilitate and inhibit how we perceive an object in the real world to influence how we conceive of that object during language comprehension. Some evidence already exists in support of this prediction. First is the tactile disadvantage effect: When told to expect words from a particular perceptual modality, people need more time to process touch-related words like *warm* or *itchy* than words relating to sight, taste, sound, or smell (Connell & Lynott, 2010). This tactile disadvantage is not due to lexical differences between the words (the same effect emerges when comparing visual and tactile processing of bimodal words such as *jagged*), but rather reflects a disadvantage in tactile attentional control found in perceptual processing (Spence, Nicholls, & Driver, 2001; Turatto, Galfano, Bridgeman, & Umiltà, 2004). The second piece of evidence is the modality switching effect: When people are asked to verify a series of perceptual properties (e.g., visual *tiger can be striped*), responses are slower after verifying a property in a different modality (e.g., auditory *whistle can be shrill*) than after verifying a property in the same modality (e.g., visual *candle can be flickering*: Lynott & Connell, 2009; Marques, 2006; Pecher, Zeelenberg, & Barsalou, 2003; van Dantzig, Pecher, Zeelenberg, & Barsalou, 2008; Vermeulen, Niedenthal, & Luminet, 2007). This modality switching cost is not due to associative priming (although see Louwerse & Connell, in press); the use of related but false filler items, such as *oven can be baked*, ensures that participants cannot rely on simple word association strategies. Rather, the effect mirrors that found in perceptual tasks, where switching modalities from one trial to the next (e.g., from a visual light flash to an auditory tone: Spence et al., 2001) incurs a processing cost because attention must be shifted from one modality-specific neural system to another.

To date, the above research examining the role of perceptual phenomena in conceptual processing has been limited by its reliance on the retrieval of familiar concepts (e.g., confirming that green can be seen, or that whistles are shrill). However, constructing new meaning from old referents is the keystone of generative language and cognition. As cognitive functioning is not confined to the repeated use of familiar words and ideas, and rather is predicated upon the ability to understand new things and represent new conceptual entities, any account of the conceptual system must be able to accommodate this constructive ability. Various theories of conceptual combination have focused on people's ability to create such novel representations from existing concepts (e.g., Costello & Keane, 2000; Smith, Osherson, Rips, & Keane, 1988; Wisniewski, 1997), but these theories have tended to be based on symbolic-computational assumptions of concepts and properties and cannot make any predictions regarding the role of modality-specific representations in the concept creation process. By concept creation, we mean representing or understanding a new concept by actively combining two already-known concepts (e.g., *shimmering tuna* as a tuna fish with glistening, iridescent scales). This active construction of a meaning for a novel combination should be clearly distinguished from simply retrieving the meaning of familiar phrases that contain two or more words. For example, interpreting the compound *cute baby* does not require the concepts *cute* and *baby* to be combined, because the compound is already lexicalized and has a strong, frequency-reinforced link between the phrasal unit and its simulation (i.e., it is easily retrievable). In contrast, a novel compound like *shimmering tuna* is missing this link and therefore requires other means to arrive at a simulation and interpretation (i.e., it must be created). Even if situational information from past experience is used in the simulation of a novel compound (e.g., fish sometimes have glistening scales, wet things often shimmer and a freshly caught tuna would be wet), the simulation process still represents concept creation because it is combining experiential information in new ways. This study therefore aims to examine the role of perceptual information in the creation of novel conceptual entities. If embodied theories are correct and perceptual simulation underlies conceptual processing, then modality switching costs should emerge in concept creation.

2. Experiment 1

Unlike previous studies of modality switching in conceptual processing, we will not utilize a property verification paradigm that asks people to respond ''yes'' or ''no'' whether an adjective property is usually true of a noun concept (e.g., *motorcycle can be loud*). Instead, we will ask participants to provide an interpretation for adjective–noun compound phrases (e.g., Lynott & Connell, 2010a; Tagalakis & Keane, 2006). The main reason for our change of task is that property verification can only be used for concept retrieval (e.g., *motorcycle can be loud* should be accepted with a ''yes'' response because motorcycles are usually loud, whereas *onion can be jingling* should be rejected with a ''no'' response because onions do not usually jingle). Compound interpretation, on the other hand, allows both concept retrieval and creation (e.g., *loud motorcycle* and *jingling onion* have no right or wrong answer and can be represented in many different ways). Thus, we present adjective–noun compounds in paired sequential trials that examine both the retrieval of familiar conceptual information (i.e., familiar → familiar pairs, replicating previous property verification studies) and the creation of new conceptual entities (i.e., novel → novel pairs). We expect familiar compounds to be processed more quickly than novel compounds because it is easier to retrieve an existing concept than to create a new one. We would also expect modality switching costs to emerge for both familiar and novel compounds—for example, slower interpretations for an auditory target when it follows a visual compound (e.g., familiar *shiny penny* → *loud motorcycle* or novel *shimmering tuna* → *jingling onion*)—because attention must be shifted between modality-specific systems.

Moreover, it should be noted that both linguistic and simulation systems are engaged upon reading a word, although the peak of linguistic activation precedes that of simulation (Barsalou et al., 2008; Louwerse & Connell, in press). Thus, fast response times to language stimuli are likely to reflect ''quick and dirty'' processing in the linguistic system (i.e., statistical information that captures associations between linguistic tokens), whereas slower response times are likely to reflect deeper processing in the simulation system (i.e., including modality-specific perceptual information). In support of this idea, Louwerse and Connell (in press) demonstrated that fast response patterns in a property verification task were more consistent with processing in the linguistic system, whereas slow response patterns were more consistent with processing in the simulation system. In a corpus analysis of modality-specific words, Louwerse and Connell showed that visual and haptic modalities are indistinguishable on the basis of linguistic information, as are olfactory and gustatory modalities. Critically, switches between these three ''linguistic modalities'' (visuohaptic, auditory, and olfactogustatory) were a better predictor of processing costs at the fast end of the response-time distribution than switches between the five conventional perceptual modalities, whereas this pattern was reversed at the slow end of the response-time distribution. In relation to the current study, by requiring participants to provide an interpretation for an adjective–noun compound (rather than respond ''yes'' or ''no'' to a property verification question), we expect that linguistic information will be superseded by more useful simulated perceptual information, and hence lead to larger modality switching costs than previously observed in conceptual processing tasks.

2.1. Method

2.1.1. Participants

Forty-eight native speakers of English took part for course credit. Two participants were excluded from the analysis for consistently pressing invalid keys during the experiment, whereas one further participant was excluded for producing more than 20% invalid interpretations.

2.1.2. Materials

One hundred forty-four adjective–noun compounds were used in this experiment: 72 familiar and 72 novel (see Appendix A). Modality-specific adjectives were taken from Lynott and Connell's (2009) modality exclusivity norms, which comprise 423 object properties with mean ratings [0–5] of how strongly that property is experienced through each of five perceptual modalities: auditory, gustatory, haptic, olfactory, and visual. In order to be considered a strongly unimodal property (i.e., predominantly pertaining to just one perceptual modality), each adjective in this experiment had the highest strength rating in its dominant modality (minimum of 3.0) and all other modalities were at least one full point lower on the ratings scale. In order to reflect the retrieval of familiar conceptual knowledge, adjectives were matched to nouns according to their presence in free association norms (Nelson, McEvoy, & Schreiber, 2004). For example, the visual property *green* was produced as a target in Nelson et al.'s norms to the cue concept of *pickle*, and so *green pickle* was generated as a familiar compound.

A candidate set of 324 novel compounds was initially generated by pairing modality-specific adjectives with nouns that do not appear as associated concepts in free-association norms. To ensure that the novel combinations gave rise to consistent and plausible interpretations, we first presented them to a different group of 40 participants (who did not take part in either Experiment 1 or 2) as part of an offline interpretation and rating task. Each participant received a sample of 108 compounds and was asked to provide an interpretation for each compound and subsequently to provide a rating (1–7 scale) of how plausible he or she found the interpretation just provided. These interpretations were then independently coded by the two authors into one of three categories: dominant modality (where the interpretation predominantly focused on the target modality of the adjective), other modality (where one or more nontarget modalities were dominant in the interpretation), or invalid (where the compound was not actually interpreted as instructed).[1] Agreement between coders was high (Cohen's $\kappa = 0.843$, $N = 4355$). A final set of 72 novel compounds was selected according to two criteria: At least 75% of participants provided an interpretation in the dominant modality ($M = 89\%$, $SD = 9\%$), and the mean plausibility rating was above 4.0 (i.e., above the midpoint of the rating scale: $M = 4.26$, $SD = 0.76$). As only one gustatory compound met these criteria, it would not have been possible to place the item in a gustatory → gustatory pair and so it was replaced with a compound from another modality.

In the final set of materials, familiar compounds had a mean frequency of 3.7 occurrences per million words in the British National Corpus (BNC, 2007) and had a mean Google phrase frequency of 159,462. This compares with a mean frequency of 0.06 occurrences for novel compounds in the BNC and a mean Google frequency of 764. Differences between the log frequencies for familiar and novel compounds were reliable when comparing BNC and Google frequencies (both ps < .0001).

We then formed pairs of adjective–noun compounds for sequential presentation by randomly selecting a compound from one modality (to be presented first) and pairing it with another compound from the same or different modality (the target item). Familiar compounds were paired together (i.e., familiar → familiar transition) as were novel compounds (novel → novel transition). Furthermore, the pairing of each target compound with its preceding modality was counterbalanced: For example, a visual target would be presented following another visual item (no-switch condition), as well as a nonvisual compound (modality switch condition). Across stimulus lists, each familiar item and each novel item appeared as both a target and nontarget items. Thus, every compound appeared in both switch/no-switch conditions and target/nontarget conditions, with every participant seeing every compound but in only one of these possible conditions. As an additional control, word associations within each pair of compounds (i.e., backwards and forwards cue–target associations from Nelson et al., 2004, for adjective1–adjective2, adjective1–noun2, noun1–adjective2, and noun1–noun2) were calculated. The level of association was extremely low across the item set, with over 99% of pairs having no associates in the above permutations. The mean associative strengths between items per condition were: familiar switch

($M = 0.00045$) and familiar no-switch ($M = 0.00014$), $p > .3$; novel switch ($M = 0.0$) and novel no-switch ($M = 0.0$), $p > .99$.

2.1.3. Procedure

Participants were instructed that they would be asked to come up with interpretations for two-word phrases (e.g., *popping balloon*, *shimmering tuna*) as quickly as they could. They were asked to try to come up with an interpretation even if the phrase was not previously known to them. They were also instructed to try to give clear, specific interpretations, avoiding vague interpretations (e.g., ''a type of tuna'') or interpretations that simply reused the original words of the phrase (e.g., ''a tuna that is shimmering'').

Each trial began with a blank screen for 250 ms followed by a central fixation cross for 250 ms. A compound then appeared in the center of the screen, and participants were instructed to press the space bar once they had a meaning in mind for the phrase. Having pressed the space bar, a text box appeared where they could type in the interpretation they had just generated. Once participants had completed typing, they pressed the enter key to move on to the next item. If participants took more than 10 s to think of an interpretation, they received some feedback asking them to try to answer more quickly. The presentation of compound pairs was randomized for each participant. Prior to the experiment proper, participants completed a set of practice trials that contained a mix of familiar and novel compounds (not used elsewhere). Participants also received a self-paced break after every 36 interpretations. The experiment took approximately 60 min to complete and, on debriefing, no participants were aware of the focus on perceptual modalities in the compounds.

2.1.4. Design and analysis

Two factors were manipulated both within-participants and within-items: familiarity (familiar or novel pairs) and modality switch (switch or no-switch), with response times for target items as the dependent variable. Both compounds in a pair had to receive a valid interpretation (using the same criteria as in materials selection) for the target response time to be included in the analysis (see Appendix B for sample interpretations). People had little difficulty with the task, with <3.6% of trials resulting in invalid interpretations. Outliers less than 400 ms or more than 2.5 *SD*s from the participant's mean per condition were removed (2.34% of data). Response times on remaining trials were analyzed using linear mixed models with crossed random effects of participants and items, which offers a more complete description of systematic sources of variance in the model than separate F_1 and F_2 analyses, particularly for unbalanced data (e.g., when invalid and outlier responses are excluded from analysis: Baayen, Davidson, & Bates, 2008; Locker, Hoffman, & Bovaird, 2007). The validity of including random effects for participants and items was tested empirically by comparing restricted log-likelihood values: From the baseline of an empty model, adding participants as a random factor significantly improved model fit, $\chi^2(1) = 1{,}057.34$, $p < .0001$, which was in turn improved by crossing the random effect of items, $\chi^2(1) = 175.07$, $p < .0001$. The final analysis thus included crossed random effects of participants and items and crossed fixed factors of familiarity and modality switch. All estimated marginal means are in milliseconds, with directional analyses for switch > no-switch comparisons.

2.2. Results and discussion

As expected, familiar compounds (M = 2311) were processed more quickly than novel compounds (M = 2870), $F(1, 137.35) = 54.81$; $p < .0001$. Overall, switching modalities between trials (M = 2627) was only marginally slower than staying within the same modality (M = 2554), $F(1, 2691.87) = 2.31$, $p = .064$, no interaction ($F < 1$). However, when we separately examine familiar and novel pairs in planned comparisons (see Table 1), we find significant modality switching costs for familiar compounds, $t(1338.70) = 2.03$, $p = .021$, but no such cost for novel compounds ($t < 1$). In other words, interpreting familiar adjective–noun compounds replicates the earlier findings in property verification tasks: Retrieving familiar conceptual information leads to processing costs when switching perceptual modalities from one trial to the next. People are slower to interpret *loud motorcycle* following *green pickle* than following *quiet museum* because attention must be shifted between modality-specific neural systems. Furthermore, such perceptual effects emerge even when participants are asked to ''come up with an interpretation for each phrase,'' which contains no instructional bias toward imagery or the relevance of perceptual information.

In addition, switching costs (116 ms) are relatively larger in the current interpretation experiment (switch condition is 5.2% slower than the no-switch condition) than in previous studies using property verification (e.g., 3.1%: Lynott & Connell, 2009; 2.8–3.8%: Marques, 2006; 2.6%: Pecher et al., 2003, Experiment 1; 1.8%: van Dantzig et al., 2008). Such an increase in processing costs is consistent with the idea that interpretation tasks require a more detailed perceptual simulation than property verification tasks and hence exert a greater hold on attention than simulations that have not reached peak activation. However, in order to determine whether relatively shallow linguistic information, rather than deeper simulation of perceptual information, could explain our findings, we conducted further analyses based on Louwerse and Connell's (in press) categorization of ''linguistic modalities.'' In a corpus analysis of the modality-specific words from Lynott and Connell's (2009) norms (i.e., the adjectives in the present compounds), Louwerse and Connell showed that they cluster on the basis of statistical linguistic information into three linguistic modalities—visuohaptic, auditory, and olfactogustatory—which means that certain pair transitions in the present experiment do not constitute a switch of linguistic modalities: visual → haptic, haptic → visual, olfactory → gustatory, or gustatory → olfactory. When we re-analyzed

Table 1
Interpretation times (estimated marginal means in milliseconds), with standard errors in parentheses, of target trials for each type of compound pair in Experiments 1 and 2

	Experiment 1		Experiment 2
Modality Switch	Familiar → Familiar	Novel → Novel	Familiar → Novel
Switch	2,364 (141)	2,881 (171)	2,648 (163)
No-switch	2,248 (141)	2,867 (171)	2,529 (163)
Switching cost	116*	14	119*

Note. *$p < .05$.

our data using this linguistic switch variable in place of the original perceptual switch variable,[2] there was no overall difference between the switch and no-switch conditions ($F < 1$), and no-switching costs for either familiar compounds, $t(1218.92) = 1.23$, $p = .11$, or novel compounds, $t < 1$. This result is consistent with Louwerse and Connell's finding that processing costs at longer response times are only predicted by switches between perceptual modalities and not linguistic modalities. Therefore, although linguistic factors play an important role in the processing of any linguistic stimuli, they cannot alone explain the observed switching cost in the present study. Rather, switching costs emerge from the simulation of modality-specific perceptual information.

However, the issue remains that interpreting novel adjective–noun compounds in this experiment showed no evidence of modality switching costs. This null effect is not due to some underlying switching costs being drowned out by difficulty or plausibility of concept creation[3]: Pretests allowed us to select only novel compounds that easily produced plausible interpretations. One possible explanation is that, as the construction ab initio of a new conceptual entity is more effortful than the retrieval of a familiar one (e.g., Tagalakis & Keane, 2006), it may therefore require attention on more than just the dominant modality in order to create a coherent multimodal simulation. For example, although people predominantly interpret *jingling onion* using the auditory modality, other modalities could also demand attention, such as the visual and haptic simulation of a musical instrument (e.g., ''an onion that makes musical noises when you shake it'') or the olfactory and gustatory simulation of food (e.g. ''an onion that makes a sound when cooked''). In order to test whether novel compounds lead to more multimodal interpretations, we randomly selected two valid interpretations per compound (half novel and half familiar) and coded them for multimodality; that is, whether a modality other than the dominant one was referenced in the interpretation. For example, the interpretation for *muttering oven* as ''a noisy oven'' was coded as unimodal because it referenced only the dominant modality (auditory), whereas the interpretation ''sizzling hot oven'' was coded as multimodal because it involved an extra modality (haptic as well as auditory). Overall, novel compounds gave rise to more multimodal interpretations ($M = 47.6\%$) than did familiar compounds ($M = 27.1\%$), $\chi^2(1, N = 288) = 7.41$, $p = .006$. As participants' written interpretations cannot include every single modality-specific aspect of the underlying simulation and are instead likely to highlight only the strongest or most attention-grabbing aspects, this coding scheme is a conservative estimate of the number of modalities being simulated. Nonetheless, as modality switching costs emerge from shifts in attentional allocation, the fact that attention appears to be frequently distributed across multiple modalities for concept creation makes switching costs less likely to emerge than for relatively unimodal concept retrieval. We pursue this issue further in the next experiment.

3. Experiment 2

If the representation of novel concepts is more multimodal than that of familiar concepts, such attentional splitting could be the reason that novel $\rightarrow$ novel pairs exhibited no-switching costs in the previous experiment: Moving from one multimodal representation to another (even if one modality is dominant) would not necessarily incur a processing penalty because the component modalities are more likely to overlap. Our goal in this experiment is therefore to present familiar → novel pairs of compounds and test whether people exhibit switching costs when they must create a new concept after attention has been captured by a single modality. In other words, we expect participants will be slower to process the predominantly auditory *jingling onion* following visual *shiny penny* than auditory *loud motorcycle* because attention must be shifted from one modality-specific neural system to another.

3.1. Method

3.1.1. Participants

Forty-two native speakers of English, who had not taken part in the previous experiment, participated for course credit. Two participants were excluded from the analysis for producing more than 20% invalid interpretations.

3.1.2. Materials

Eighty test compounds (40 familiar, 40 novel) were selected from those used in the previous experiment and arranged into familiar → novel pairs so that each target item appeared in both the switch and no-switch conditions (although every participant saw a given compound in only one of these possible conditions). As before, there were no differences between switch and no-switch conditions in terms of associative strength between target and nontarget items with more than 99% of compound pairs having no backward or forward associates (switch $M = 0.01$; no-switch $M = 0.01$, $p > .99$). Finally, in order to avoid repeated alternation of familiar and novel compounds, test items were supplemented with an additional 88 filler compounds that were arranged into pairs using a mix of transitions (i.e., familiar–familiar, novel–novel, familiar–novel, novel–familiar). Presentation of test and filler pairs was randomized per participant.

3.1.3. Procedure

The procedure was followed as in Experiment 1, with the exception that participants received a self-paced break after every 42 interpretations due to the slightly larger number of trials.

3.1.4. Design and analysis

A single factor of modality switch (switch or no-switch) was manipulated both within-participants and within-items, with response times for target items in valid pairs as the dependent variable. Outliers <400 ms or more than 2.5 *SD*s from the participant's mean per condition were removed (2.40% of data). As before, we empirically tested the validity of including random effects for participants and items in a linear mixed model. From an empty model baseline, adding participants as a random factor significantly improved model fit, $\chi^2(1) = 455.62$, $p < .0001$, which was in turn improved by crossing the random effect of items $\chi^2(1) = 58.16$, $p < .0001$. The final analysis thus included crossed random effects of participants and items and the fixed factor of modality switch.

3.2. Results and discussion

Switching costs emerged as predicted: Novel compounds were 4.7% slower to interpret when they were preceded by a familiar compound from a different perceptual modality than the same modality (see Table 1), $t(1422.47) = 1.70$, $p = .045$. As before, these switching costs disappeared when the data were analyzed according to Louwerse and Connell's (in press) linguistic modality categories, $t(1371.47) = 1.10$, $p = .135$, showing that the critical effect is more simulated perceptual than linguistic in nature.

In an additional analysis, we examined how interpretations of novel compounds related to their dominant modality and the modality of the preceding trial[4] by selecting a sample of target interpretations (four per compound: two from the switch condition and two from the no-switch condition, randomly chosen). Each interpretation was then coded with three separate criteria according to whether a particular modality was referenced in the interpretation: the dominant modality, the preceding modality, and a chance modality (randomly chosen modality that was neither the dominant nor preceding one). Overall, the dominant modality featured consistently often in switch (86%) and no-switch conditions (90%), $\chi^2(1, N = 160) = 0.54$, $p = .46$, similar to the 89% rate in offline pretests. However, in the switch condition, the modality of the preceding trial featured in target interpretations only at a rate of chance: 19% versus 21%, respectively, $\chi^2(1, N = 160) = 0.16$, $p = .69$. For example, although people may mention sound-related information in their interpretations of the visually dominant *handsome guitar* (e.g., ''a good looking and sounding guitar''), this could happen regardless of whether the preceding trial had focused on the auditory modality.

In sum, concept creation requires perceptual simulation. People are slower to simulate a novel concept (e.g., auditory *jingling onion*) when their attention has already been engaged by a different modality in simulating a familiar concept (e.g., visual *shiny penny*). Nonetheless, such previous attentional engagement does not necessarily mean that the situated simulation of a novel concept will adopt the prior modality when another modality is strongly dominant.

4. General discussion

Modality switching costs emerge during concept creation as well as concept retrieval. People are slower to create a new conceptual entity in a particular perceptual modality (e.g., auditory *jingling onion*) when attention has previously been captured by conceptual processing in a different perceptual modality (e.g., visual *shiny penny*). The novel findings reported here add to the body of evidence in support of perceptual simulations of conceptual information. For example, neuroimaging and electrophysiological studies show that sensorimotor regions are activated during semantic word processing (e.g., ''cinnamon'' activates the primary olfactory area of the piriform cortex: González et al., 2006; see also Goldberg, Perfetti, & Schneider, 2006; Hauk, Johnsrude, & Pulvermüller, 2004; Simmons et al., 2007). Furthermore, behavioral studies have shown that people represent implied perceptual information during sentence comprehension even though doing so does not facilitate task performance (e.g., Connell, 2007; Connell & Lynott, 2009; Kaschak et al., 2005; Lynott & Coventry, unpublished data; Stanfield & Zwaan, 2001), and that perceptual phenomena such as modality switching costs (van Dantzig et al., 2008; Lynott & Connell, 2009; Marques, 2006; Pecher et al., 2003) and the tactile disadvantage (Connell & Lynott, 2010) emerge in conceptual processing. Critically, our present findings show that this conceptual-to-perceptual dependence is not just restricted to concept retrieval but also generalizes to concept creation. In this light, our findings also offer the first evidence for the role of modality-specific perceptual information in the online processing of novel compounds, and for perceptual simulation in conceptual combination (see also Wu & Barsalou, 2009).

Furthermore, our data suggest that creating a new conceptual entity requires a greater degree of multimodality in its perceptual simulation than retrieving a familiar entity. Representing a new concept for the first time is likely to involve quite a lot of perceptual, motor, affective, and other information that is not necessarily internal to the concept (see also Wu & Barsalou, 2009). For example, a *beige panda* can reasonably be interpreted as just ''a panda with beige fur,'' but many of our participants gave detailed information in their interpretations that suggested they were situating their simulations in a wider context to explain the panda's unusual color (e.g., ''a wild animal that eats bamboo and looks like it has been rolling around in the sand,'' ''panda wearing human skin-colored make up,'' ''a panda with albinism''; see also Appendix B). The holistic nature of these representations means that attention will be demanded by many perceptual modalities, not just the dominant visual modality required for color. This multimodality account is consistent with the collective evidence of both studies, and we suggest this is why switching costs were negligible (0.5%) for novel compounds in Experiment 1: novel $\rightarrow$ novel transitions are essentially multimodal $\rightarrow$ multimodal transitions and do not necessarily entail an attentional shift. In contrast, it is easier to simulate a more unimodal representation of a familiar concept—one that highlights only a subset of the possible modalities—because its very familiarity affords greater flexibility. If one has simulated the look, sound, smell, taste, and touch of a *green pickle* many times before, then it is relatively easy to focus attention on just one of these modalities—particularly the visual modality highlighted by the adjective—when interpreting the phrase. For this reason, substantial switching costs (5.2%) emerged for familiar compounds in Experiment 1: familiar $\rightarrow$ familiar transitions entail shifting attention from one relatively unimodal representation to another. Slightly smaller switching costs (4.7%) emerged for novel compounds in Experiment 2 because familiar $\rightarrow$ novel transitions require an attentional shift between a relatively unimodal representation and a multimodal representation in which a different perceptual modality is dominant. In short, simulation during concept creation is relatively multimodal because the new concept is automatically situated in a broader context, whereas simulation during concept retrieval *can be* relatively unimodal because it is possible for attention to highlight frequently experienced aspects of the constituent concepts.

Switching costs in compound interpretation are proportionally larger than those observed in property verification tasks (about 5% compared to ~2%), which is in line with views of embodied cognition that describe parallel roles for both linguistic information and perceptual simulation. Barsalou's Language and Situated Simulation (LASS) theory (Barsalou et al., 2008; see also Louwerse & Jeuniaux, 2008) extends the perceptual symbol systems view (Barsalou, 1999) to incorporate nonsimulation factors that affect language processing. Barsalou and colleagues describe a linguistic system that is engaged rapidly and tends to reach peak activation extremely rapidly, which contrasts with the simulation system that is engaged similarly rapidly but tends to have much later peak activation. The implication is that the linguistic system can therefore offer a useful shortcut for relatively shallow processing of language stimuli, but deeper conceptual processing will require perceptual simulation. The compound interpretation task employed in this paper requires representing detailed information, which is a deeper form of conceptual processing than responding yes or no in a property verification task. Consequently, there is less of an opportunity for a linguistic shortcut in compound interpretation than in property verification tasks, and the greater reliance on the simulation system gives rise to larger switching costs (see Lynott & Connell, 2010b, for a detailed discussion of the complementary roles of the linguistic and simulation systems during conceptual combination).

However, it is important to note that the LASS framework does not negate or relegate the role of linguistic factors; rather, it suggests different time courses and levels of activation for the two systems. So is it possible for linguistic factors to explain the present results? Our analyses indicate not. Words that pertain to the various perceptual properties do indeed cluster according to their distributional information (Louwerse & Connell, in press), but such clusters are imprecise because words relating to sight and touch are indistinguishable (e.g., many share the context of handling concrete objects), as are words relating to smell and taste (e.g., many share the context of food), with only auditory properties distinct. This imprecision is important because our results show no reliable switching costs between these three linguistic modalities (visuohaptic, olfactogustatory, and auditory). Rather, switching costs only emerge when more precise transitions between all five perceptual modalities (visual, haptic, olfactory, gustatory, and auditory) are examined.

Previous research has shown that modality switching costs emerge during concept retrieval when attention shifts between perceptual modalities (e.g., van Dantzig et al., 2008; Lynott & Connell, 2009; Marques, 2006; Pecher et al., 2003; Vermeulen et al., 2007). We have shown that switching costs also emerge during concept creation. Together, these findings indicate that conceptual representation consists of a situated simulation using the same modality-specific neural substrates involved in perception.

Notes

1. Any interpretations that were blank or nonsensical, or that failed to detail the meaning of the compound—for example, typological definitions of the noun (e.g., *bloody dagger* as "a type of dagger"), syntactic rearrangements of the compound (e.g., "a

dagger that is bloody''), or simple word associations (e.g., ''Macbeth'')—were excluded as invalid.

2. The ratio of switch:no-switch trials was approximately 45:55 using the linguistic modality variable, as opposed to 50:50 for the previous perceptual modality variable.
3. Presenting novel adjective–noun compounds does not necessarily rule out the possibility that people are retrieving some existing concept usually labeled with a different word or phrase (we thank Diane Pecher for raising this point), a phenomenon that Costello and Keane (2000) refer to as known-concept interpretations (e.g., interpreting *stilt bird* as a flamingo, rather than as a bird walking around on stilts). In order to examine whether our participants were creating new-concept or known-concept interpretations for our novel compounds, we examined a sample of 144 interpretations (two per compound, randomly selected). In total, only five interpretations (3.5%) of responses could be classified as known-concept interpretations: For example, biological taxonomy notwithstanding, one of our participants interpreted *smelly porcupine* as ''a skunk.'' Therefore, we are confident that straightforward retrieval of known concepts is relatively rare, and that participants are creating novel situated simulations for novel compounds.
4. We thank Diane Pecher for this suggestion.

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References

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, *59*, 390–412.

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

Barsalou, L. W., Santos, A., Simmons, W. K., & Wilson, C. D. (2008). Language and simulation in conceptual processing. In M. De Vega, A. M. Glenberg, & A. C. Graesser (Eds.), *Symbols, embodiment, and meaning* (pp. 245–283). Oxford, England: Oxford University Press.

The British National Corpus, Version 3 (BNC XML Edition), (2007). *Distributed by Oxford University Computing Services on behalf of the BNC Consortium*. Available at: http://www.natcorp.ox.ac.uk.

Collins, A. M., & Quillian, M. R. (1969). Retrieval time from semantic memory. *Journal of Verbal Learning and Verbal Behaviour*, *8*, 240–248.

Connell, L. (2007). Representing object colour in language comprehension. *Cognition*, *102*, 476–485.

Connell, L., & Lynott, D. (2009). Is a bear white in the woods? Parallel representation of implied object color during language comprehension *Psychonomic Bulletin & Review*, *16*, 573–577.

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

Costello, F. J., & Keane, M. T. (2000). Efficient creativity: Constraint-guided conceptual combination. *Cognitive Science*, *24*, 299–349.

van Dantzig, S., Pecher, D., Zeelenberg, R., & Barsalou, L. W. (2008). Perceptual processing affects conceptual processing. *Cognitive Science*, *32*, 579–595.

Fodor, J. A. (1975). *The language of thought*. New York: Crowell.

Gallese, V., & Lakoff, G. (2005). The brain's concepts: The role of the sensory-motor system in reason and language. *Cognitive Neuropsychology*, *22*, 455–479.

Gibbs, R. W. (2003). Embodied experience and linguistic meaning. *Brain and Language*, *84*, 1–15.

Gibbs, R. W. (2006). *Embodiment and cognitive science*. New York: Cambridge University Press.

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review*, *9*, 558–565.

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

González, J., Barros-Loscertales, A., Pulvermüller, F., Meseguer, V., Sanjuán, A., Belloch, V., & Ávila, C. (2006). Reading cinnamon activates olfactory brain regions. *Neuroimage*, *32*, 906–912.

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

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*, B79–B89.

Katz, J. J., & Fodor, J. A. (1963). The structure of a semantic theory. *Language*, *39*, 170–210.

Kintsch, W., & van Dijk, T. A. (1978). Toward a model of text comprehension and production. *Psychological Review*, *85*, 363–394.

Locker, L., Hoffman, L., & Bovaird, J. A. (2007). On the use of multilevel modeling as an alternative to items analysis in psycholinguistic research. *Behavior Research Methods*, *39*, 723–730.

Louwerse, M., & Connell, L. (in press). A taste of words: Linguistic context and perceptual simulation predict the modality of words. *Cognitive Science*.

Louwerse, M. M., & Jeuniaux, P. (2008). Language comprehension is both embodied and symbolic. In M. de Vega, A. Glenberg, & A. C. Graesser (Eds.), *Embodiment and meaning: A debate* (pp. 309–326). Oxford, England: Oxford University Press.

Lynott, D., & Connell, L. (2009). Modality exclusivity norms for 423 object properties. *Behavior Research Methods*, *41*, 558–564.

Lynott, D., & Connell, L. (2010a). The effect of prosody on conceptual combination. *Cognitive Science*, *34*, 1107–1123.

Lynott, D., & Connell, L. (2010b). Embodied conceptual combination. *Frontiers in Cognition*, *1*(216), 1–14.

Marques, J. F. (2006). Specialization and semantic organization: Evidence for multiple semantics linked to sensory modalities. *Memory & Cognition*, *34*, 60–67.

Nelson, D. L., McEvoy, C. L., & Schreiber, T. A. (2004). The University of South Florida word association, rhyme, and word fragment norms. *Behavior Research Methods, Instruments & Computers*, *36*, 402–407.

Newell, A., & Simon, H. A. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice Hall.

Pecher, D., Zeelenberg, R., & Barsalou, L. W. (2003). Verifying properties from different modalities for concepts produces switching costs. *Psychological Science*, *14*, 119–124.

Pecher, D., & Zwaan, R. A. (2005). *Grounding cognition: The role of perception and action in memory, language, and thinking*. Cambridge, England: Cambridge University Press.

Pylyshyn, Z. W. (1984). *Computation and cognition*. Cambridge, MA: MIT Press.

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*, 2802–2810.

Smith, E. E., Osherson, D. N., Rips, L. J., & Keane, M. (1988). Combining prototypes: A selective modification model. *Cognitive Science*, *12*, 485–527.

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

Stanfield, R. A., & Zwaan, R. A. (2001). The effect of implied orientation derived from verbal context on picture recognition. *Psychological Science*, *12*, 153–156.

Tagalakis, G., & Keane, M. T. (2006). Familiarity and relational preference in the understanding of noun-noun compounds. *Memory & Cognition*, *34* (6), 1285–1297.

Tulving, E. (1972). Episodic and semantic memory. In E. Tulving & W. Donaldson (Eds.), *Organization and memory* (pp. 381–403). New York: Academic Press.

Turatto, M., Galfano, G., Bridgeman, B., & Umiltà, C. (2004). Space-independent modality-driven attentional capture in auditory, tactile and visual systems. *Experimental Brain Research*, *155*, 301–310.

Vermeulen, N., Niedenthal, P. M., & Luminet, O. (2007). Switching between sensory and affective systems incurs processing costs. *Cognitive Science*, *31*, 183–192.

Wisniewski, E. J. (1997). When concepts combine. *Psychonomic Bulletin & Review*, *4*, 167–183.

Wu, L., & Barsalou, L. W. (2009). Perceptual simulation in conceptual combination: Evidence from property generation. *Acta Psychologica*, *132*, 173–189.

Appendix A

Familiar and novel adjective–noun compounds used in Experiment 1.

Familiar compounds

Auditory: laughing audience, popping balloon, beeping horn, booming bomb, loud motorcycle, deafening crash, quiet museum, rhythmic melody, screaming monster, thunderous applause.

Gustatory: fruity grape, lemony tea, sour juice, spicy mustard, cheesy macaroni, juicy berry, buttery bagel, bland oatmeal, eggy omelet, oniony soup.

Haptic: aching back, fluffy pillow, heavy iron, warm radiator, feverish headache, gooey substance, greasy vaseline, hot oven, jagged edge, rough surface, slimy oyster, sticky gum, cool ice, crisp flake, spiky thorn, tight knot, moist lips, adhesive sticker.

Olfactory: musky aftershave, musty attic, antiseptic cream, fishy clam, pungent cheese, scentless soap, smoky room, reeking breath, sweaty armpit, whiffy socks, stenchy odor, aromatic spices.

Visual: broken cup, glossy lipstick, khaki shorts, patterned curtains, sunny morning, ugly portrait, yellow lawn, dazzling spotlight, green pickle, transparent paper, bloody dagger, bright jewel, blue horizon, broad shoulder, purple orchid, cute baby, metal robot, dirty ashtray, gold trophy, high peak, silver coin, polished nail, bulky sweater.

Novel compounds

Auditory: creaking axe, echoing wheel, jingling onion, buzzing table, howling nut, meowing hawk, mumbling school, soundless rain, muttering oven, husky lizard, rustling worm, squealing ink, whispering tent, noisy cornflakes, squeaking jungle.

Haptic: hard duck, chilly tire, cold tiger, damp chicken, freezing desk, icy gut, spiky train, pulsing skull, prickly dungeon, gooey cigarette, smooth trousers, scratchy water.

Olfactory: odorous wall, smelly porcupine, stinky thumb, perfumed castle, scented wave.

Visual: beautiful helmet, bent owl, blonde compost, bronze cigar, curly mountain, dark grenade, filthy pan, flowery moon, handsome guitar, little parachute, long chick, orange badger, big ketchup, glowing vase, gray catapult, motionless smoke, oval midge, rippled horse, shallow freckles, vivid noodle, compact elbow, gleaming sofa, cloudy knee, skinny bin, square tongue, bursting grass, white harp, beige panda, crinkled attic, cute engine, scrawny well, forked cannon, tall rope, polished flapjack, transparent bladder, foamy zebra, small deodorant, shimmering tuna, floral crow.

Appendix B

Sample valid interpretations produced by participants in Experiment 1.
Novel compound: *jingling onion.*

An onion that makes a jingling sound when you move it.
A onion that makes musical noises when you shake it.
A bunch of onions being shaken as if they were bells.
An onion that makes a noise when it is moved.
Onion with clanging bells around the edge.
A small onion that jingles when shaken.
An onion which sounds like bells.
Onion making the sound of multiple high-pitched bells.
The tinkles that the knife makes when it meets the board when chopping onions.
An onion on a chain of onions making a noise.

Familiar compound: *loud motorcycle.*

A bike with a loud engine.
An engine of a motorcycle making a very loud roaring noise.
A fast motorcycle that makes an awful noise.
A motorcycle that makes a loud noise when the engine is revved.
The roaring exhaust of a motor bike as it races past.
A motorcycle which makes a loud revving noise.
The revving noise a bike makes as it prepares to go.
A motorbike with a noisy engine.
A motorcycle whose owner likes to show off so they rev the engine to make sure they get the attention that they crave.
A motorcycle with a large engine that can be heard coming up the street.