Multi-Modal Simulation in Conceptual Processing

Lawrence W. Barsalou[1], Diane Pecher[2], René Zeelenberg[2],

W. Kyle Simmons[1], Stephan B. Hamann[1]

[1] Emory University

[2] Erasmus University Rotterdam

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Address correspondence to:

Lawrence W. Barsalou
Department of Psychology
Emory University
Atlanta, GA 30322
(404) 727-4338
barsalou@emory.edu
http://userwww.service.emory.edu/~barsalou/

Over the course of the Medin Festschrift, we heard a lot about Doug's intellectual qualities and contributions. Certainly these are impressive and significant. Nevertheless, one thing that I've learned from adopting the embodied perspective on cognition is that this perspective often leads one to notice new things not seen from other perspectives. Given the strong cognitive orientation of most participants here, it is perhaps not surprising that we have focused so far on Doug's intellectual qualities. It might be interesting, though, to think about Doug from the embodied perspective. Perhaps we will see new qualities not noticed before.

One such quality was revealed by an event that occurred the day before the Festschrift. On my flight from Atlanta to Chicago, I wore bike riding shorts, because I was going to ride the bike path along Lake Michigan after arriving. Notably, these shorts do not have a belt. Furthermore, the belt that I usually take on a trip is the one that I wear on the plane. Because I was not wearing a belt, I arrived in Chicago without one. As a result, I found myself standing around holding up my pants that evening at Sandy Waxman's welcoming party. Then a most fortuitous event occurred (especially for this story). As I was leaving the party, I ran into Doug in Sandy's front yard and asked if he could bring me a belt the next morning. Being the extremely generous guy that he is, Doug took off his belt on the spot and handed it to me. I'm sure that Sandy's neighbors are still talking about this. More importantly, though, when I put on the belt, it was about three inches too short, which I found surprising, given that I'm in pretty good physical condition. The thought that ran immediately through my mind was, "Wow, Doug is in great shape." As anyone who has spent a few days with Doug knows, he exercises religiously and eats carefully, with the result being his gazelle-like figure. This is one of Doug's embodied qualities that might be missed from a purely cognitive perspective.

Another of Doug's most notable embodied qualities is how intensely he blushes. When I pointed this out at the workshop, true to form, Doug produced one of his most intense and beautiful blushes ever. Making Doug blush is a favorite pastime of his friends. As these examples illustrate, the embodied approach does lead one to remarkable new insights about the world.

Seriously, the thing that has impressed me the most about Doug ever since I have known him is his openness to different perspectives and new ideas. Not only is he open to them, he often embraces divergent views and ideas simultaneously. Doug is the epitome of the so-called Eastern cognitive style. In situations where different views might be viewed as mutually exclusive and contradictory, Doug instead sees them as complementary, contributing multiple levels of explanation to a common problem.

One classic example is that Doug has championed both exemplar models and intuitive theories in his research. On many occasions, I've heard people wonder how the same person could possibly have embraced both ideas. If you recognize Doug's ability to perceive different views as complementary pieces of a common puzzle, however, it makes total sense. For him, exemplar models and intuitive theories both capture important insights about the human conceptual system.

Another more mundane example comes from an invited talk that Doug gave at the Cognitive Science Society Conference in Ann Arbor during the summer he moved from Illinois to Michigan. On his title slide, Doug listed his affiliation as the "University of Michigan at Urbana-Champaign." Rather than viewing university affiliation as mutually exclusive, Doug identified simultaneously with both institutions (perhaps hoping that both might continue to pay his salary).

Finally, Doug spent a sabbatical at Emory in the mid-1980s while Linda was doing a clinical internship there. Something that really struck me about Doug's stay were his visits to the Emory library. Doug was over there all the time, and after returning, he would often stop by and tell me what he had found. One notable aspect of these reports was the breadth of things that Doug was reading. He was not just perusing articles on categorization, nor just articles in cognitive psychology, nor just articles in psychology. To the contrary, Doug was all over the map. He was reading articles from all sorts of literatures that I would have never considered exploring.

A second notable aspect of Doug's library reports was how open he was to completely different ideas and findings, and how much he allowed them to influence his thinking. Doug clearly has high standards and is not easily drawn to weak findings. Nevertheless, when Doug found something good, he was not only open to it, he learned from it, even when it differed from positions he currently held. In my opinion, this openness to different perspectives and new ideas is one central factor that underlies Doug's impressive intellect and contributions to the field.

In this spirit, the work reviewed in this chapter comes from two methodological perspectives: cognitive psychology and cognitive neuroscience. In current times, this is hardly a novel combination, but at least it resonates with the theme that developing multiple perspectives on a common problem is a productive way to gain leverage.

Assumptions about Category Representation

Three theoretical assumptions underlie the current research in my laboratory. First, we assume that simulations of experience often represent categories. As people represent *TREES*, for example, they simulate experiences of them.[1] Increasing behavioral and neural evidence supports this conclusion (e.g., Barsalou, 2003b; Barsalou, Niedenthal, Barbey, and Ruppert, 2003; Martin, 2001). Second, we assume that a simulation is a partial reenactment of the modality-specific states that arise as people experience a category's members. People's simulations of *TREES*, for example, are partial reenactments of the perceptual, motor, and introspective states that occur as people actually experience them. For more detailed accounts of this simulation process, see Damasio (1989), Barsalou (1999, 2003a), and Simmons and Barsalou (2003). Our third assumption is that category representations tend to be multi-modal—a theme that will be central in the research reviewed here. When people simulate a category, they do not typically simulate it on just one modality. Instead, they simulate it on multiple modalities that are likely to be relevant. For example, when people represent *TREES*, they not only simulate their visual properties, but also how trees might smell and sound. Following Cree and McRae (2003), we assume that different profiles of multi-modal information represent different types of categories.

Predictions

If the conceptual system utilizes modality-specific systems for representational purposes, then a general prediction follows: Phenomena that occur in modality-specific systems should also occur in conceptual processing. Not every modality-specific phenomenon should be observed (e.g., low-level input processes to sensory systems), but at least some should.

Modality-switching costs in perception. In this chapter, the modality-specific phenomenon of interest is the shifting of attention from one modality to another during perceptual processing. As much work has shown, such shifts incur temporal costs. Because it takes time to disengage attention from one modality and engage it in another (e.g., Posner & DiGirolamo, 2000), a delay arises before the processing of signals on a new modality can begin.

Consider an experiment that illustrates this phenomenon. In Spence, Nicholls, and Driver (2000), participants were presented with stimuli on three modalities: light flashes in vision, tones in audition, and vibrations on the skin. On a given trial, only one stimulus was presented, sampled randomly from one of the three modalities. Each signal occurred either to the left or to the right of the participant, whose task was to indicate, as quickly as possible, on which side the stimulus occurred.

Of primary interest was whether switching modalities from one signal to the next incurred a processing cost. Because modalities were sampled randomly, two consecutive stimuli sometimes occurred on the same modality, and sometimes switched from one modality to another. A light flash, for example, could have been preceded by another light flash, a tone, or a vibration.

Spence et al. found that switching modalities from one trial to the next incurred a cost. For each modality, participants were about 40 ms slower when the modality differed on the previous trial than when it remained the same. One interpretation is that the modality processing the current signal engages the attentional system. When the subsequent trial occurs on the same modality, attention need not shift modalities to process the stimulus. Conversely, when the subsequent trial occurs on a different modality, attention must shift, thereby incurring a temporal cost.

Modality-switching costs in conceptual processing. As a post doctoral student in my laboratory, Diane Pecher began searching for perceptual phenomena that might operate in higher cognition. On discovering modality-switching costs in perception, Pecher had the hunch that these costs might also arise during conceptual processing. If people use modality-specific simulations to represent the properties of objects, then different kinds of properties should be simulated in different modalities. Furthermore, if two properties are simulated on different modalities, there should be a cost associated with shifting attention from one modality to the other as each is simulated in turn.

Consider an example. Imagine that a participant is asked to verify the property *moos* for the category *COW*. If the simulation view is correct, participants should simulate the sound of mooing in the auditory system, and then assess whether the simulated property occurs in a simulated cow (for more detailed accounts of the property verification process, see Solomon & Barsalou, 2001, 2004). Further imagine two different verification trials that could precede the verification of *COW-moos*: *CHALK-squeaks* vs. *HONEY-sweet*. Because *squeaks* is also an auditory property, attention need not shift modalities to subsequently simulate *moos*—attention can remain in the same modality. Conversely, because *sweet* is a gustatory property, attention must shift from the gustatory to the auditory modality to simulate *moos*. As a result of this shift, verifying *moos* should take longer to verify following *squeaks* than following *honey.* If the conceptual system utilizes modality-specific systems to represent concepts and their properties, then the cost for switching modalities in perceptual processing should also occur in conceptual processing.

To explore modality-switching costs in conceptual processing, Diane Pecher initiated and performed three lines of research patterned after modality-switching experiments in perception. The remainder of this chapter reviews these projects.

Modality Switching in Conceptual Processing: Behavioral Experiments

All the experiments reviewed in this section share the following methodological properties. First, the basic task that participants performed was property verification. On a given trial, a participant verified one or two properties for a given concept, depending on the particular experiment. When verifying single properties, a participant might verify *BLENDER-loud*. When verifying two properties, a participant might verify *CAVE-chilly, humid*.

In each study, the critical verification trials sampled properties from four to six modalities: vision, audition, action, touch, taste, and/or smell. Because the availability of properties differs considerably across modalities, the number of properties used for different modalities typically varied. Whereas many properties exist in vision and audition, relatively few exist in taste and smell. In general, though, we have observed modality-switching effects for all modalities. In a given experiment, most but not all modalities typically produce a difference in the predicted direction. Across experiments, every modality produces such differences some times.

The key manipulation across studies was whether the modalities of two properties—a context property followed by a target property—were the same or different. A given target property (e.g., *BLENDER-loud*) was sometimes preceded by a context property from the same modality (e.g., *LEAVES-rustling*), and was sometimes preceded by a context property from a different modality (e.g., *CRANBERRY-tart*). A given participant never received both the same-modality and different-modality context properties for a target property. Although each participant received every critical property, they received half with context properties from the same modality, and half with context properties from a different modality, with the assignment of same vs. different context to target properties counter-balanced across participants.

The number of critical trials was typically smaller than the number of filler trials, such that the critical trials were not salient. Furthermore, the number of consecutive trials on the same modality constituted a relatively small proportion of the total trials. Thus, the critical pairs of trials blended in continuously with the filler trials such that the critical pair-wise structure of the materials was not apparent. For the different trials, all possible combinations of modalities were used. The critical pairs were distributed randomly through the list and were never blocked in any way. On each trial, participants typically received the name of a concept, followed by the phrase "can be," followed by a property word, on three lines (e.g., *HAIR* / can be / *fair*). Participants were told that, for a true response, a property simply had to be possible of its respective concept. Finally, the properties used on false trials typically had some sort of relation to their respective concepts (e.g., *BUFFALO-winged, BUTTERFLY-bird*), thereby preventing participants from using the presence vs. the absence of relations as a basis for responding (Kan, Barsalou, Solomon, Minor, & Thompson-Schill, 2003; Solomon & Barsalou, 2004).

Verifying Individual Properties for a Concept

Experiment 1 from Pecher, Zeelenberg, and Barsalou (2003) illustrates both the basic paradigm and the basic findings obtained in it. On the critical trials, a given participant verified a property either from the same vs. different modality as the property on the previous trial. Of interest was whether this context manipulation affected the time to verify the target properties. If participants simulate the properties in modality-specific systems, they should verify the target properties faster when they do not have to switch modalities after verifying the context properties than when they do. To assess whether the relative onset of the concept and property plays a role in this phenomenon, the SOA from the concept to the property was manipulated between participants (0 ms vs. 260 ms).

At both SOAs, participants were slower to verify properties when they had to switch modalities than when they did not. When the SOA was 0 ms, the switching cost was 29 ms; when the SOA was 260 ms, the switching cost was 20 ms. The lack of an effect for SOA is consistent with previous findings from our laboratory showing that modality-specific effects occur across SOAs that range from 0 ms to 1600 ms (Solomon, 1997; Solomon & Barsalou, 2001, 2004). Errors did not differ significantly between same vs. different modalities, averaging around 5%. These results support the hypothesis that participants simulate properties in modality-specific systems as they verify them.

Recently, Marques (2004) replicated this finding, observing a similar switching effect of 36 ms. Marques further showed that this switching effect occurred for both natural kind categories (41 ms) and for artifact categories (31 ms). More importantly, he showed that the switching effect is not the result of shifting from one conceptual domain to another. Unlike our studies, Marques held the conceptual domain constant between two target trials. Whenever a target property belonged to a natural kind (e.g, *DOG-bark*), the same and different context properties also belonged to natural kinds (e.g., *BEE-buzz* vs. *LOBSTER-rough*). Conceptual domains were similarly held constant for artifacts (for the target property *TELEPHONE-ring*, the same vs. different context properties were *CLOCK-tick tock* vs. *MIRROR-reflect*). Under these conditions, Marques still observed a switching effect, indicating that uncontrolled shifts in conceptual domains are not responsible.

Experiment 2 in Marques (2004) offers further support. This experiment manipulated the conceptual domain across two consecutive trials while holding the modality of the property constant. For example, participants verified the auditory property, *DOG-bark* either after verifying an auditory property for another natural kind (*LION-roar*), or after verifying an auditory property for an artifact (*CLOCK-tick tock*). This manipulation had no effect on time to verify the target properties. Participants were equally fast regardless of whether the conceptual domain remained constant or changed. Solomon and Barsalou (2001) similarly found that concept similarity had little impact on property verification. Thus, the basic switching effect is not the result of changing the conceptual domain but instead appears to be the result of changing the property modality.

Finally, Marques' (2004) experiments presented concept and property words in Portuguese. The finding that switching costs occur in multiple languages further demonstrates their robustness.

Assessing the Role of Associative Strength Between Properties

Another alternative account of the modality-switching effect must be considered. Imagine that properties from different modalities are all stored in a single conceptual system. Further imagine that stronger associations exist, on the average, between properties from the same modality than between properties from different modalities. Stronger associations could develop between properties from the same modality for a variety of reasons. Regardless, the presence of such associations could explain the modality-switching effect. When a context and target property are both from the same modality, the context property activates an association to the target property, which speeds processing.

Two preliminary facts argue against this interpretation of the modality-switching effect. First, we assessed the associative strength between properties from the same modality vs. properties from different modalities and found no difference. Based on the Nelson, McEvoy, and Schreiber (1999) word association norms, the associative strength between critical property pairs was essentially 0 for both the same- and different-modality materials.

The lexical priming literature offers a second piece of evidence against the associative strength account. Much research shows that the associative priming produced on a trial dissipates very soon thereafter. Typically, associative priming is mostly observed on a stimulus that immediately follows the priming stimulus. When intervening material occurs, little if any priming is observed (e.g., Masson, 1995). In our modality-shifting experiments, intervening material resides between each pair of consecutive properties. Consider the following pair of trials: *LEAVES* / can be / *rustling* / fixation point / *BLENDERS* / can be / *loud*. As this example illustrates, a fixation point and three words (*BLENDERS* / can be) intervene between the two properties (*rustling*, *loud*), elapsing over about 3 sec. Significant opportunity exists for priming from *rustling* to dissipate before *loud* is encountered.

These two problems for the associative account suggest caution in adopting it. Nevertheless, we thought it important to address this account directly. Thus, Experiment 2 of Pecher et al. (2003) manipulated the associative strength between two consecutive properties. In some pairs, the two properties were very highly associated in the Nelson et al. (1999) norms (e.g., *spotless-clean*, *polyester-cheap*); in other pairs, the two properties were unassociated (e.g., *polyester-clean*, *spotless-cheap*). For example, one participant verified the pair, *SHEET-spotless*, *AIR-clean*, whereas a different participant verified the pair, *SHIRT-polyester*, *AIR-clean*. The average associative strength between the associated properties was unusually high (i.e., higher than 95% of words in the norms to their highest associate). Conversely, the unassociated pairs of properties never co-occurred a single time in the norms. According to Nelson (personal communication, Jan. 23, 2002), manipulations of this size typically produce large differences in experiments where associative strength has effects.

This experiment produced a modality-switching effect of 41 ms, replicating our previous result. More importantly, however, associative strength had no effect. Associated pairs of properties were 1 ms slower than unassociated pairs. If associative strength had been responsible for our previous results, the strong manipulation of associative strength should have produced a large effect. The absence of such an effect argues strongly against this interpretation. Even if properties from the same modality were more associated than properties from different modalities, any such associative advantage does not produce a priming effect in this paradigm. Instead, the intervening material between the two properties appears to cause any priming from the first property to dissipate. The best remaining account of the switching effect appears to be that shifting attention between modalities is responsible. We consider further alternative accounts of these results in the final discussion

Simultaneously Verifying Two Properties for a Concept

To assess the generality of the modality-switching effect, we performed additional experiments using different paradigms and different materials in another language, Dutch. In these experiments, participants verified two properties for the same concept, rather than one. The first of these experiments assessed whether the modality-switching effect occurs when participants verify two properties simultaneously for the same concept, either from the same or different modalities. The second of these two experiments assessed whether the modality-switching effect occurs when participants verify two properties sequentially for the same concept over the course of a couple minutes. If we observe modality-switching effects in these other paradigms, this would indicate that the modality-switching phenomenon does not just result from one set of experimental conditions. Because the first experiment has not been reported elsewhere, we report it in detail here.

As previous experiments have illustrated, a modality-switching effect occurs when the property modality switches from one trial to the next. If our interpretation of this account is correct, we should also be able to obtain this switching effect when two properties are presented simultaneously for the same concept. When the two properties are from the same modality, verification should be faster than when they are from different modalities. Thus, participants should be faster to verify two somatosensory properties for a concept (e.g., *CAVE-chilly, humid*) than to verify one somatosensory property and one visual property (e.g., *CAVE-chilly, dark*). Of course, the time to verify the individual properties must be comparable (e.g., *humid* vs. *dark*), such that individual verification times do not compromise this comparison. Furthermore, two properties from the same modality should not be more associated than the two properties from different modalities. To ensure that these two methodological requirements were met, additional scaling studies showed that individual verification times and associative strength were comparable in the same vs. different conditions.

Subjects and materials. Fifty-six native Dutch speakers at Utrecht University participated for a small monetary fee. The critical materials were 64 concrete concepts (e.g., *CAVE*) presented in Dutch, with each concept being assigned three properties (e.g., *chilly, humid, dark*). One property was designated as the target property, and the other two were designated as context properties from either the same vs. different modality. All target properties came from one of four modalities: 16 from vision (e.g., *brown, striped*), 16 from motor action (e.g., *peel, shake*), 16 from touch (*hot, rough*), and 16 from sound (e.g., *creaking, humming*). Given the paucity of available properties in taste and smell, enough could not be obtained to construct a fully balanced design. Different-modality properties came from the four modalities used for the target properties, and also from taste and smell.

An additional 64 concepts were used for false trials, each presented with one true property and one false property. Half the time, the properties were from the same modality, and half the time they were from different-modalities, thereby mirroring the distribution of modalities on the true trials. An additional 32 concepts were used for practice trials. Analogous to the critical materials, same vs. different modality and true vs. false were manipulated orthogonally.

Two different lists were created for counterbalancing purposes. In each, 32 critical concepts were paired with their target property and the same-modality property; the remaining 32 critical concepts were paired with the target property and the different-modality property. Each concept was paired with the similar modality property in one list and with the different-modality property in the other. Each participant saw each concept and property only once.

Procedure. On each trial, a fixation stimulus first appeared at the center of the screen for 500 ms. A concept name and two property names were then presented simultaneously. The concept name appeared where the fixation stimulus had been. The two property names appeared four lines below, horizontally adjacent to each other. On critical trials, the target property was always presented on the right, so that its position was held constant as the same-modality property vs. different-modality property varied on the left. On false trials, false properties appeared equally often on the left and right.

Participants were instructed to assess whether both properties were possible of the concept as quickly and accurately as possible. When both properties were true, participants pressed the ?/ key on the computer keyboard; when one property was false, they pressed the z key. Following incorrect responses, the message 'FOUT' ("error") appeared for 1000 ms, followed by a 1000 ms blank screen. If the response was slower than 3000 ms, the message 'TE LANGZAAM' ("too slow") appeared for 1000 ms, followed by a 500 ms blank screen. If the response was correct and faster than 3000 ms, no message appeared, and the next trial began 500 ms after the response. Participants received a short break every 40 trials. During the break, participants were shown the percentage of errors made during the preceding block. If the percentage was higher than 15%, the participant was instructed to make fewer errors. If the percentage was lower than 5%, participants were told that their performance was excellent. When ready, participants began the next block of trials by pressing the space bar.

Scaling studies. Two scaling studies were performed to ensure that confounding factors were not present in the materials. The first assessed whether the time to verify the same vs. different context properties for the target properties differed in verification time when presented alone. Ideally, the time to verify the same-modality vs. different-modality properties should be the same. An additional 56 Dutch participants verified the critical concepts paired with individual properties. On some trials, participants verified a single same-modality property for a concept; on others, they verified a single different-modality property for a concept (the target properties were not tested). A given participant only received one context property for a given concept, never both, with the assignment of properties to participants counter-balanced across lists.

No differences in median RTs or errors were found between same-modality vs. different-modality properties. Different-modality properties (1047 ms) were verified as quickly as same-modality properties (1054 ms) ($t(54) = 0.54$, $SE = 12.74$). Further, different-modality properties (12.2 %) had similar error rates as same-modality properties (11.8%) ($t(54) = 0.53$, $SE = 0.64$). As these results indicate, any difference between same- vs. different-modality properties in the main experiment cannot be attributed to differences in verifying individual properties.

A second scaling study assessed whether the target properties were equally associated to their respective same-modality vs. different-modality context properties. Each target property was presented in isolation to 26 additional Dutch participants with instructions to produce the first word that came to mind in a free association task. No participant received both the same-modality vs. different-modality property. The results showed that the two context properties were equally unassociated to the target properties. In both cases, the likelihood of producing a target property to a context property was less than 1%. Specifically, the same-modality properties produced their respective target properties on 0.30% of the trials, and the different-modality properties produced them 0.12% of the time. These percentages did not differ reliably ($t(126) = 1.02$, $SE = 0.18$, $p > .25$). Thus, any difference between same vs. different-modality properties in the main experiment cannot be attributed to differences in their associative strength to the target properties.

Results. RTs were excluded either when the participant erred on a target trial, or on the preceding context trial.[2] To minimize outlier effects, the median RT and error rate for each participant in the same- and different-modality conditions were entered into group analyses. Participants were 54 ms faster when verifying two properties for the same concept from the same modality than from different modalities ($F(1,55) = 10.90$, $MSE = 7{,}481.9$, $p < .01$; 1536 ms same, 1590 ms different). Similarly, participants were 2.1% more accurate when verifying two properties for the same concept from the same modality ($F(1,55) = 4.14$, $MSE = 28.8$, $p < .05$; 12.4% same, 14.5% different).

These findings corroborate those obtained in the original modality-switching paradigm (Marques, 2004; Pecher et al., 2003). As we saw there, modality-switching effects occur when properties for two different concepts are processed sequentially. As we just saw here, they also occur when two properties for the same concept are processed simultaneously. Again, these results occurred even though the associative strength between properties from the same modality was no higher than the associative strength between properties from different modalities. Indeed, there was virtually no associative strength between properties from the same modality. Thus, the observed difference between same vs. different-modality properties appears to result from shifting attention between modalities. When processing must shift from one modality to another, a temporal cost is incurred.

Sequentially Verifying Two Properties for a Concept Across a Lag

This next study aimed to further generalize the modality-switching phenomenon across task conditions. As we just saw, a modality-switching effect occurs when two properties are verified simultaneously for the same concept. This next experiment assesses whether a modality-switching effect occurs when two properties are verified at different times for the same concept, separated by intervening verification trials for other concepts.

In Pecher, Zeelenberg, and Barsalou (2004), participants verified a single property for a concept on each trial. Unlike the experiments in Pecher et al. (2003) and Marques (2004), however, participants verified a second property for the same concept later on a second trial, with the intervening number of trials ranging from 12 to 100. Imagine that participants verified *APPLE-green* on a target trial. On an earlier context trial (at least 12 trials beforehand), a participant either verified a same-modality property for the same concept (*APPLE-shiny*) or a different-modality property (*APPLE-tart*). As in the previous experiment, properties were only used from four modalities: vision, audition, action, and touch. Again, the materials were presented in Dutch.

Of interest was whether the modality for the context property affected verification of the target property. If verifying *APPLE-shiny* produced a visual simulation for *shiny*, visual properties other than *shiny* might have been included in the simulation and thus been more available on the later *APPLE* trial. Conversely, if verifying *APPLE-tart* produced a gustatory simulation for *tart*, other gustatory properties might have become more available instead. Later, on the target trial for *APPLE*, if the target property had been active on the earlier context trial, it should be verified more quickly than if it had not been active earlier. Thus, verifications should tend to be faster when the modality on the context and target trials was the same than when they were different.[3]

To assess the longevity of any facilitory effect, the lag between the two properties ranged from 12 to 100 intervening trials (approximately 36 sec to 5 min, given that a single trial took about 3 sec). The distribution of filler trials masked the critical structure of the design.

The modality-switching effect occurred in the sequential lag paradigm. For lags of 12 and 18 trials, significant modality-switching effects of 34 and 42 ms occurred, respectively. At longer lags of 24 and 100 trials, the effect disappeared (7 and –3 ms). Analogously, error rates were significantly higher on different trials than on same trials, but only at the shorter lags. For lags of 12 and 18 trials, the switching costs were 3.0% and 3.1%, in contrast to insignificant costs of 1.5% and 1.3% for lags of 24 and 100.

These findings further demonstrate that the modality-switching effect is robust, occurring in still another paradigm. Furthermore, these findings show that the modality-switching phenomenon is not always present. Although the phenomenon occurred at lags of 12 and 18 trials, it did not occur at lags of 24 and 100 trials. The absence of an effect at these longer lags is noteworty—the modality-switching phenomenon is not an obligatory consequence of our materials, design, and procedures. There are conditions under which this phenomenon does not occur.

Summary of the Behavioral Results

We began with the modality-switching phenomenon in perception. When people must detect a perceptual stimulus, they incur a processing cost when switching from one modality to another. Switching attention between modalities takes time.

As we have seen across multiple lines of work, an analogous switching cost arises during conceptual processing. When people must verify a property, they incur a temporal cost when a previous property was verified on a different modality. This result suggests that people represent the properties by simulating them on the relevant modalities. When two consecutive simulations use the same modality, processing is faster than when the modalities differ. Similar to perceptual processing, shifting attention from one modality to another takes time.

As we further saw, modality-switching effects in conceptual processing do not require a narrow set of experimental conditions. We saw that these effects not only occur for English materials, they also occur for Portuguese and Dutch materials. We also saw that these effects arise in a variety of different task contexts. Modality-switching effects occur for two sequential properties that belong to different concepts. They also occur for two properties from the same concept, verified either simultaneously or with an intervening lag of 12 to 18 trials.

Two alternative accounts of the modality-switching effect have been ruled out. This effect does not reflect the similarity of two concepts whose properties are being verified (Marques, 2004; Solomon & Barsalou, 2001). Nor does the modality-specific effect reflect associative strength (Pecher et al., 2003). Thus, the best account of our effect to date is that it reflects the time to shift attention between modalities as different conceptual properties are simulated.

Multi-Modal Simulations in Conceptual Processing: An fMRI Experiment

If modality-specific simulations represent properties during conceptual processing, then a neural prediction follows: As people process properties on different modalities, the respective modality-specific areas of the brain should become active. Imagine that participants receive a block of eight trials where the properties to be verified all come from the same modality. As people verify a block of visual properties, brain areas that process vision should become active. Analogously, as people verify a block of auditory, motor, touch, taste, or smell properties, the respective brain areas that process the property type should become active. Diane Pecher designed and executed an fMRI experiment to test this prediction, with the assistance of Stephan Hamann, an fMRI researcher. Once the data had been collected, Kyle Simmons played the primary role in performing the extensive data analysis required. Simmons, Pecher, Hamann, Zeelenberg, and Barsalou. (2004) provide a detailed report of this experiment.

Method

While lying in an fMRI scanner, 12 Emory undergraduates, all native speakers of English, performed two critical tasks: property verification and lexical decision. Within a given block of 8 properties from a modality, 4 trials were true, and 4 were false, with all properties—true and false—being from the same modality. Because the number of available properties varies widely across modalities, the number of blocks varied correspondingly: 6 for vision, 6 for action, 5 for auditon, 2 for touch, 2 for taste, 1 for smell.

Two blocks of lexical decision trials were included so that the brain activation associated with word processing could be measured and subtracted from the brain activation associated with property verification. All non-words violated English rules of orthography and phonology. Because participants could identify non-words on the basis of letter and phoneme level information, accessing conceptual information was not necessary. By measuring the activation for superficial word-level processing during lexical decision and later subtracting it from the activation measured for property verification, minimal activation for conceptual processing was subtracted.

Predictions

If each block of properties activates its respective modality-specific areas, then activation in these areas should be observed. Visual properties should activate visual areas, auditory properties should activate auditory areas, and so forth.

In a blocked fMRI design, however, the activation measured for a particular block of trials is the cumulative activation across every processing event in the block. Because each block not only presents properties but also concepts, there are two potential sources of brain activation: properties *and* concepts. Although properties might only activate their respective modality-specific areas, concepts might be more likely to activate multiple modalities, given that the instances of a concept are typically experienced on multiple modalities, not just one (e.g., foods are experienced in vision, action, touch, taste, and smell). Furthermore, if the concepts for different blocks of properties vary in their distributions of multi-modal properties, different patterns of brain activation due to concepts (not just to properties) should arise across the different blocks.

Still another possibility is that properties themselves produce multi-modal activation. Intuitively many properties appear to be experienced on multiple modalities. For example, the property *shaken* for *BOTTLE* is not only experienced motorically, but can also be experienced visually, somatosensorily, and auditorally.

If multimodal activation is observed, it raises two questions. First, can the multimodal patterns of activation be predicted by the multi-modal content of the concepts and properties processed during property verification? If we scale the multimodal content of the concepts and properties in each block, can we predict the distributions of brain activity across modality-specific systems? For example, if the concepts and properties in a block of trials have relatively little taste and smell content, do we observe relatively little activation in the brain's taste and smell areas? Conversely, if the concepts and properties in a block of trials have relatively large amounts of taste and smell content, do we observe higher levels of activation in these regions?

The second question is whether the multi-modal content of the properties vs. the multimodal content of the concepts better predicts brain activation. One possibility is that blocking the trials by property modality causes the content of the properties to dominate brain activity. Because participants receive blocks of properties from the same modality, they are likely to become aware of these modalities, such that heightened activation on the modality for the current property type occurs. Alternatively, the concepts could dominate the activation process because they are the first stimulus processed on each trial. The concepts could also dominate because of their pragmatic importance. If an object were being processed in the real world, a multi-modal representation of all its relevant content would become active and maintained until processing was complete. Although particular properties might become focal at various points, the entire representation of the concept would remain active in the background. From this perspective, the property verification task involves assessing and updating an overall representation of a concept. Although a property is being assessed, a more complex and complete concept representation frames the task context. As a result, the concept drives brain activation more than the property.

Scaling the Multi-Modal Content of Concepts and Properties

Twelve additional Emory students, all native speakers of English, rated the critical concepts and properties for their multi-modal content. Half the participants rated the concepts first, and half rated the properties first. For a given concept or property, a participant judged it on all six modalities. For each modality, a participant was asked to rate, "When you experience *X*, how much of your experience involves *Y-ing* it?" *X* was a particular concept or property (e.g., *BOTTLE, creaking*), and *Y-ing* was a particular modality (seeing, hearing, acting on, touching, tasting, smelling). Every participant rated all six modalities blocked together for each concept or property, randomly ordered.

The scaling results indicated that the concepts had multi-modal content. The concepts in a given type of property block typically had considerable amounts of content on several modalities. Furthermore, the multi-modal content varied considerably across the different blocks of property trials. Different sets of concepts appeared to have different distributions of multi-modal content.

The scaling results similarly demonstrated multi-modal content for the properties. It was definitely *not* the case that each group of properties only had content on its target modality. Like the concepts, but to a lesser extent, the properties had content on multiple modalities. Interestingly, the visual properties came the closest to being uni-modal, but even they were clearly multi-modal. Properties on the other modalities were even more multi-modal, often having high values on at least two modalities. Notably, we attempted to select the most uni-modal properties that we could find throughout the research projects reviewed here. To some extent, we must have been successful, given the modality-switching effects observed. Nevertheless, it is interesting and informative to find that properties are not typically uni-modal.[4]

Analyzing and Accounting for Brain Activation

To assess the brain activation for property verification, we established maps of the activation observed on this task, one map for each of the six types of property blocks. Each map represented the average level of activation across 2x2x2 mm voxels in a three dimensional brain. We then established an analogous map for activation in the lexical decision task. To remove the activation for lexical level processing from the activation for property verification, the map for lexical decision was subtracted from each of the six maps for property verification, one per property type. The remaining activation represented the brain areas engaged in conceptual-level processing for the properties from a given modality. All of the remaining analyses were performed on the remaining activation.

To establish the particular brain areas that were significantly active for property verification, a relatively strict criterion was adopted (within the context of a random effects analysis). A significantly active brain area had to contain at least 7 contiguous voxels, and to have an uncorrected p value of less than .001. Once these significantly active clusters were identified for each property type, each active cluster was assessed for whether it fell into one of the brain's six modality-specific systems. Standard assignments of Brodman areas to sensory-motor systems were used to assign significant clusters to the visual, auditory, motor, and somato-sensory systems. Recent neuroimaging findings on localizing taste and smell areas in humans were used to assign significant clusters to these two systems. Once significant clusters had been assigned to the six sensory-motor systems, the total number of voxels across clusters was summed for each system.

The results clearly indicated that blocks of property verification trials produced multimodal—not unimodal—activation. For example, blocks of visual property verification trials did not just activate visual brain areas, but a variety of other modality-specific systems as well. Furthermore, different types of property blocks activated different patterns of modalities. As described earlier, this raises the question of whether the content of the concepts and properties explains these differing profiles of multimodal brain activation.

To assess this issue, the voxel counts obtained from the neuroimaging subtractions were regressed onto the scaling results for the concepts and properties. In two individual regressions, the voxel counts were regressed once onto just the concept scaling, and then again onto just the property scaling. Both the concept scaling and the property scaling explained significant variance in the voxel counts, with the concept scaling being more important. Whereas the concept scaling correlated .63 ($p < .0001$) with the voxel counts, the property scaling correlated .36 ($p < .01$). Thus, both the concepts and the properties processed during verification predicted the multimodal patterns of brain activation. To assess the joint contribution of the concepts and properties, a multiple regression using both scalings was performed. Together, the concepts and properties exhibited a multiple correlation of .70 ($p < .0001$) with the voxel counts.

These results suggest several preliminary conclusions that await confirmation from further research. First, it appears possible for intuitive scalings of conceptual content to predict brain activation. In this experiment, the subjectively scaled distribution of multi-modal content for concepts and properties successfully predicted the distributed patterns of activation across the brain's sensory-motor systems. People's subjective experience of concepts and properties appeared to accurately index the underlying brain activity associated with processing them. By no means do we claim that all conceptual processing is conscious. To the contrary, substantial amounts of conceptual processing are undoubtedly unconscious. Nevertheless, enough representative samples of this activity appear to become conscious such that people's subjective experience reflects their underlying neural activity.

Discussion

Two general conclusions follow from the work reviewed here. First, when people represent a particular property during conceptual processing, they simulate it in the relevant modality-specific system. Second, because concepts have properties on multiple modalities, multi-modal simulations represent them. Furthermore, because different types of concepts have different distributions of properties across modalities, different types of concepts have different multi-modal representations.

Alternative Accounts

Participants at the Medin Festschrift suggested four alternative accounts of our findings, which have been suggested elsewhere as well. We address each in turn.

Strategic set. Perhaps strategic set produces facilitation when verifying two properties from the same modality. As McKoon and Ratcliff (1995) demonstrated, when a common semantic relation exists across trials, participants detect it. As a result, participants adopt a strategic set that influences the processing of subsequent trials. To see this, imagine that participants receive a block of lexical decision or naming trials that consists of sequentially presented antonyms (e.g., *black, white, strong, weak, heavy, light*, etc.). Alternatively, imagine that participants receive sequentially presented superordinate and basic categories (e.g., *vehicle, car, clothing, shirt, tool, hammer,* etc.). During the first sequence, participants develop the strategic set that they will see antonym pairs. During the second, they develop the set that they will see taxonomic pairs. Most importantly, the set adopted affects the processing of a subsequent pair. Thus, if participants next receive *beautiful* and then *ugly*, they process *ugly* faster if they're under the antonym set than if they're under the taxonomic set.

Perhaps strategic set similarly produced facilitation for same-modality pairs relative to different-modality pairs in our experiments. After verifying one visual property, for example, a strategic set developed that facilitated verifying a subsequent visual property.

Several factors argue against this account. First, establishing strategic set typically requires many trials of the same type. In much early work, strategic set was established by making 80% of the trials consistent with the set (e.g., Posner & Snyder, 1975). Lower percentages of set-consistent trials, say 20%, were typically not sufficient. In our experiments, the proportions of properties from particular modalities were quite low, relative to the total trials. More importantly, the numbers of consecutive trials from the same modality were even lower. Consider the composition of the 300 critical trials in Experiment 1 of Pecher et al. (2003). Within these 300 trials, there were 299 opportunities to perceive a pair of trials (i.e., trials 1-2, trials 2-3, trials 3-4, …, trials 299-300). Within these 299 opportunities, only 25 (8%) contained consecutive properties from the same modality. Within these 25 opportunities, only 4 to 7 (1 to 2%) contained consecutive properties from a particular modality (e.g., visual properties). Furthermore, these critical pairs of trials were dispersed randomly throughout the list, thereby making the critical structure difficult, if not impossible, to perceive.

Based on the strategic set literature, far too little opportunities existed in these experiments for developing the set that consecutive properties should come from the same modality. Consecutive properties from the same modality were relatively few and far between. When queried after an experiment, participants never noted that pairs of trials came from the same modality. If the materials established any strategic set, the most likely form it would have taken is that two consecutive properties came from different modalities. A change in modality was, by far, the most dominant relation experienced between pairs of trials. If strategic set had operated in these experiments, participants should have been faster on different-modality trials than on same-modality trials, given that the former were more likely.

Semantic fields in a single amodal system. Another possible account of our results is that, within a single amodal system of knowledge, properties from a given modality constitute a semantic field. When one property from a modality is encountered, it activates its semantic field, which in turn facilitates the processing of other properties from the same modality.

Two findings from the experiments here pose problems for this account. First, when we assessed the associative strength between properties from the same modality, we typically found no association. In Experiment 1 of Pecher et al. (2003), two properties from the same modality never co-occurred in the Nelson et al. (1999) norms. Similarly, when we scaled properties in the unpublished study in which participants verified two properties simultaneously, we observed associative strengths less than 1%. If properties from the same modality reside in a common semantic field, one would think that they would be associated much more highly than this. For one property to activate another via a semantic field requires such associations. The lack of associations between properties from the same modality constitutes a problem for this account.

Another problem is that associative strength does not appear responsible for the modality-switching effect. As we saw earlier, when Pecher et al. (2003) manipulated associative strength between consecutive properties, it had no effect on the time to verify target properties. If an associative structure like a semantic field were responsible for the modality shifting effect, one would expect that related properties should prime one another across consecutive trials.

Vector similarity in a single amodal system. Feed-forward neural networks (along with other vector-based approaches to representation) offer yet another account of our results. Imagine that input units code the features of an object on different modalities, and that hidden units recode input activation into amodal vectors that capture the similarity between objects. When two objects share many input features, the amodal vectors that represent them conceptually are highly similar (e.g., the vectors for two animals). Conversely, when two objects share few features, their amodal vectors differ considerably (e.g., the vectors for one animal and one artifact). Analogously, the vectors that represent the *properties* of concepts should be more similar when they arise on the same modality than on different ones (e.g., the vectors for two colors vs. vectors for a color and a sound).

This architecture explains the modality switching effect. When a context property is processed, it activates a vector, which primes similar vectors. When the target property is processed, its vector benefits from this priming if it is sufficiently similar to the context property. Because two properties from the same modality have similar vectors, the first primes the second. Conversely, no priming occurs for properties from different modalities because their vectors differ too much.

Our behavioral data do not rule out the vector-similarity view. Findings from other studies, though, raise problems for it. First, it does not explain the wide spread finding that conceptual representations are distributed across modality-specific systems. According to vector similarity theories, the vectors that represent conceptual knowledge reside in a unitary amodal store. Problematically, though, much work, including Simmons et al. (2004) reviewed earlier, demonstrates that distributed representations become active across modalities to represent the multi-modal content of concepts (for a review, see Martin, 2001). These findings pose a problem for any unitary amodal theory, including vector similarity theories.

A second problem is that much behavioral research shows that sensory-motor variables affect conceptual processing. Consider some examples. Zwaan, Stanfield, and Yaxley (2002) found that reading about objects activates perceptual representations of their shapes. Solomon and Barslaou (2001) similarly found that shape affects property priming. Stanfield and Zwaan (2001) found that reading about objects activates perceptual representations of their orientations. Solomon and Barsalou (2004) found that the size of visual properties affects verification speed. Wu and Barsalou (2004) found that occlusion affects the production of visual properties.

It is not clear how amodal vectors in a unitary conceptual store explain such findings. If amodal vectors represent objects during conceptual and linguistic tasks, then why should the shape, orientation, and size of these objects affect processing? Why should occlusion matter? Standard accounts of amodal vectors assume that they abstract over these low-level details of perceptual representations, distilling out the abstract features that remain. Behavioral effects of sensory-motor variables on conceptual processing are difficult to reconcile with this view.

Distributed systems of amodal symbols in modality-specific systems. Still another potential account of our results is that each modality contains a separate system of amodal symbols for representing the modality's conceptual content. For example, amodal symbols in the visual system represent the visual properties of concepts, amodal symbols in the motor system represent the action properties of concepts, and so forth. On this view, the modality shifting effect occurs because attention must switch between different sets of amodal symbols, as property verification switches from one modality to another.

This move by proponents of the amodal view significantly undermines their enterprise. Traditionally, the amodal view has assumed that semantic memory is a unitary store of knowledge that is separate from sensory-motor systems and also from the episodic memory system (e.g., Tulving, 1972). From this perspective, knowledge has little, if anything, to do with modality-specific systems. Conceptual knowledge has certainly never been viewed as residing in the brain systems that perform perception and action. Instead the default view has been that a unitary amodal system of knowledge contains the properties of concepts somewhere else in the cognitive architecture.

Thus, to now claim that amodal sets of symbols are distributed across modality-specific systems—and to indeed reside within them—is a major move towards the embodied position. It acknowledges the importance of the modalities in the representation of knowledge.

Furthermore, it is no longer clear that such symbols are amodal. If they are amodal, why are they stored in modality-specific systems? If such symbols reside in modality-specific systems, it would seem likely that they are modality-specific representations.

This account also fails to explain why sensory-motor variables such as shape, orientation, size, and occlusion have behavioral effects on conceptual findings. Again, if amodal symbols represent objects during conceptual and linguistic tasks, then why should shape, orientation, size, and occlusion have effects? Regardless of whether amodal symbols reside in a unitary store or are distributed across modalities, they neither predict nor explain these findings. The distributed account of amodal symbols is designed to explain only the modality shifting effect. Problematically, it fails to explain these other results, which the simulation view explains naturally.

Conclusions

Adopting the embodied approach shifts attention from well-traveled roads of inquiry to less familiar ones. As recent reviews of the embodiment literature indicate (e.g., Barsalou, 2003b; Martin, 2001), adopting the embodied approach changes the variables that researchers manipulate (e.g., occlusion) and the dependent variables that they measure (e.g., bodily states). In the work reviewed here, the embodied view led us to assess whether the modality shifting effects that occur in perception also occur in conception. The embodied view also led us to assess whether different concepts and properties have different profiles across the brain's modality-specific systems. Prior to this work, traditional amodal theories have not led researchers to ask such questions. Regardless of whether the embodied view turns out to be correct, it will at least lead researchers to ask new questions, to perform new types of experiments, and to integrate methods and theories in new ways across disciplines.

The adventurousness and unconventionality of this approach is not unlike Doug Medin's roving intellect over the course of his fine (and continuing) career. Most fortunately, his adventurous and unconventional spirit appears to have rubbed off on quite a few of us. May we continue to pass it on to our own students, and they to theirs.

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Address correspondence to Lawrence W. Barsalou, Department of Psychology, Emory University, Atlanta, GA 30322 (barsalou@emory.edu, http://userwww.service.emory.edu/~barsalou/), or to Diane Pecher, Department of Psychology, Erasmus University Rotterdam, Postbus 1738, 3000 DR Rotterdam, The Netherlands (pecher@fsw.eur.nl).

Footnotes

[1] Italics will be used to indicate concepts, and quotes will be used to indicate linguistic forms (words, sentences). Thus, *TREES* indicates a concept, and “trees” indicates the corresponding word. Within concepts, uppercase words will represent categories, whereas lowercase words will represent properties of categories (e.g., *TREES* vs. *leaves*).

[2] RTs for target trials were removed when subjects erred on the previous context trial because an assessment of modality switching assumes that subjects processed both the context and target trials correctly. When subjects erred on a context trial, a variety of complicating factors could affect processing on the target trial.

[3] Episodic memories could also play a role in a facilitory effect. If verifying *APPLE-shiny* produced a visual simulation for *shiny*, the long-term memory of the trial should contain an association to the visual system, such that the simulation of *shiny* could be retrieved at a later time. Later, on performing the target trial for *APPLE*, the association to the previous property’s simulation could direct participants’ attention to the respective modality. Thus, if the previous verification was for *shiny*, participants should subsequently verify *green* more rapidly than if the previous verification was for *tart*.

[4] Frederico Marques reported informally to us that Portuguese property names appear even less uni-modal than English property names, suggesting that interesting cross-linguistic differences may exist in the multi-modal representation of properties.