Cognitive Science 31 (2007) 183–192

Switching Between Sensory and Affective Systems Incurs Processing Costs

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Received 7 June 2006; received in revised form 31 July 2006; accepted 1 August 2006

Abstract

Recent models of the conceptual system hold that concepts are grounded in simulations of actual experiences with instances of those concepts in sensory-motor systems (e.g., Barsalou, 1999, 2003; Solomon & Barsalou, 2001). Studies supportive of such a view have shown that verifying a property of a concept in one modality, and then switching to verify a property of a different concept in a different modality generates temporal processing costs similar to the cost of switching modalities in perception. In addition to non-emotional concepts, the present experiment investigated switching costs in verifying properties of positive and negative (emotional) concepts. Properties of emotional concepts were taken from vision, audition, and the affective system. Parallel to switching costs in neutral concepts, the study showed that for positive and negative concepts, verifying properties from different modalities produced processing costs such that reaction times were longer and error rates were higher. Importantly, this effect was observed when switching from the affective system to sensory modalities, and vice-versa. These results support the *embodied cognition* view of emotion in humans.

Keywords: Embodied cognition; Affects; Simulation; Concepts; Knowledge; Emotion

1. Introduction

Shifting attention from processing in one sensory modality, such as vision, to another, such as audition, involves temporal processing costs (e.g., Posner & DiGirolamo, 2000). For instance, Spence, Nicholls and Driver (2001) showed that when experimental participants had to detect the left–right location of stimuli that were presented in one of three possible sensory mo-

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dalities, they were slower to make a response if a different (compared to the same) modality had been presented on the previous trial.

A number of experiments have recently relied on the phenomenon of modality switching costs to test predictions of models of conceptual representation that assume that concepts are grounded in states of activation in sensory-motor systems. Such theories of *embodied cognition*, propose that higher order cognition involved in memory, language use, and judgment operates directly on simulations in sensory-motor systems rather than on abstract symbols that constitute redescriptions of the neural states that were active during knowledge acquisition or initial experience (e.g., Barsalou, 1999; Glenberg, 1997). In this view, then, using one's concept of *AIRPLANE* when planning a vacation, for instance, involves simulations of being in an airplane in visual, auditory, and for many of us, affective, systems.

If conceptual processing involves the reactivation of sensory-motor states then modality switching costs should also be apparent in conceptual tasks. This effect was demonstrated by Pecher, Zeelenberg and Barsalou (2003). In their studies, participants performed a property verification task in which the to-be-verified properties represented one of six sensory modalities (vision, audition, taste, touch, olfaction, and action). For instance, on a given trial participants might have verified that *CRANBERRIES* are *tart*. Data analyses examined the speed of property verification when the property that had been verified on the previous trial was in the same modality (e.g., *LEMON-sour*) versus a different modality (e.g., *BLENDER-loud*). Indeed, when the property verified on the previous trial represented a different modality, switching costs incurred (see also Pecher, Zeelenberg, & Barsalou, 2004).

And, neuroimaging studies provide additional support for modality-specific simulations in conceptual processing (Kan, Barsalou, Solomon, Minor, & Thompson-Schill, 2003; Simmons, Martin, & Barsalou, 2005).

Although evoked in many examples, such as our example of the concept of an *AIRPLANE*, the role of affective systems in grounding concepts has not been studied (for discussion, see Niedenthal, Barsalou, Ric & Krauth-Gruber, 2005 and Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005). However, the possibility that affective features of concepts are simulated using the same systems as those that support affective responses to an object or event when directly experienced is suggested by a number of research findings. Studies of fear learning show that when participants are verbally instructed to expect a shock paired with a specific CS, and are later presented with that CS, they display arousal responses that are similar to those that are displayed after Pavolvian fear conditioning, in which the actual shock is present (e.g., Hugdahl & Öhman, 1977; Phelps, O'Connor, Gateby, Grillon, Gore, & Davis, 2001). Such findings indicate that the affective response that has been associated with a class or objects or events can be simulated in the absence of direct exposure to an instance of a given class.

Still, that affective simulation *can occur* and the question of whether simulations *constitute conceptual content* are different issues. In the present view, processing the affective nature of an object or event involves simulation in the affective response systems, including the autonomic nervous system, the facial musculature, and subcortical structures such as the amygdala (e.g., Olsson & Phelps, 2004, Phelps et al., 2001). Judging that an object is or can be frightening, friendly, or frustrating should therefore incur switching costs if a prior judgment involved verification of an auditory or visual property of a different object.

The present experiment assessed switching costs in a property verification task in which some target concepts were affectively charged, and possible properties to verify were represented in one of two sensory modalities (vision and audition) or, of greatest interest, the affective system. We asked whether switching from a sensory modality to the affective system incurs temporal processing costs. Evidence of such costs would provide additional evidence in favor of embodied theories of conceptual processing as well as specific evidence in favor of the grounding of concepts in the affective system.

2. Method

2.1. Subjects and Design

Eighty-one volunteers (73 women) from the Catholic University of Louvain at Louvain-la-Neuve (Belgium) served as participants in fulfilment of a course requirement. The mean age of the participants was 19.62 years ($SD = 1.01$). The study was introduced as part of a program of research on the speed of conceptual processing, and no mention was made of an interest in emotion. The study conformed to a 3 (Valence: neutral, positive, negative) × 2 (Modality context: same, different) × 2 (Modality type: sensory, affective) fully within-subject design.

2.2. Materials

A set of 144 concept–property associations was developed. The first 48 associations (i.e., 33 %) were neutral and were selected from the critical trials used by Pecher, Zeelenberg and Barsalou (2003). Properties were selected from vision, taste, motor actions and audition. For the remaining associations, 96 French nouns (i.e., 48 negative concepts and 48 positive concepts) were selected from validated words lists (Messina, Morais, & Cantraine, 1989; Niedenthal, Auxiette, Nugier, Dalle, Bonin, & Fayol, 2004; Syssau & Font, 2005). Words that had high emotionality scores as well as either a highly negative score or a highly positive valence score were selected for use in the study. For the negative and the positive concepts, we selected 16 properties from (the relevant) affective states (e.g., *upset, jolly*), 16 from vision (e.g., *khaki, elongated*), and 16 from audition (e.g., *babbling, deafening*).

From the 144 concept–property associations, 72 pairs were formed (i.e., one context association followed by one target association). Half were formed by two different concepts coupled with properties from the same modality (e.g., *TRIUMPH–exhilarating* / *COUPLE–happy*), and half were formed by two different concepts coupled with properties from different modalities (e.g., *FRIEND–tender* / *TREASURE–bright*) (see Table 1). For each participant, associations were randomly assigned to be part of the same modality pairs or to be part of the different modality pairs. Moreover, due to the random assignment, the two associations of each pair had the same probability of being selected for a context trial or target trial. All 144 critical concept–property associations were true, meaning that the property was true for its respective concept. Importantly, we did not cross the valence of the *CONCEPT–property* associations within pairs. This means that that a positive *CONCEPT–property* association could only be paired

Table 1
Examples of the critical target and context trials from the three valences

			Context Trial	
Valence	Modality	Target Trial	Same Modality	Different Modality
Neutral	Taste	*CUCUMBER–bland*	*BUTTERMILK–sour*	*PIG–sniffing*
Neutral	Visual	*CHEDDAR–orange*	*CEMENT–gray*	*KEYS–jingling*
Negative	Affective	*VICTIM–stricken*	*ORPHAN–hopeless*	*SPIDER–black*
Negative	Visual	*TANK–khaki*	*WOUND–open*	*SOB–moaning*
Positive	Affective	*TRIUMPH–exhilarating*	*COUPLE–happy*	*VICTORY–sung*
Positive	Auditory	*BABY–babbling*	*LAUGHTER–heard*	*ROSE–red*

with a positive *CONCEPT–property* association, the same was true for negative associations as well as neutral ones.

In addition to the critical pairs, there were also filler trials designed to mask the aim of the experiment. Because critical trials contained more emotional associations than non emotional associations, the reverse was true in the filler trials. The experimental trials included 180 pairs, 72 of which were critical (i.e., 48 were emotional, 24 were neutral) and 108 pairs were fillers, for a total number of 360 trials. For the 48 emotional pairs, we had four pairs in each condition (e.g., four same negative affective pairs). Of the 108 filler pairs, 72 included two false properties (i.e., 48 were neutral and 24 were emotional), 18 contained a true trial then a false trial (i.e., 6 neutral, 6 positive and 6 negative), and 18 contained a false trial then a true trial (i.e., 6 neutral, 6 positive and 6 negative). Consistent with Pecher et al. (2003), properties of the fillers referred not only to specific modalities but also to properties that could be represented in multiple modalities. Moreover, concept and property of many false trials were semantically associated to ensure that the participants had to process properties in order to correctly reject false trials (e.g., *CAR–asphalt*; *GUN–guiltless*). All concepts and properties were used only once. Training trials were composed of 12 true concept–property associations and 12 false concept–property associations different from those used in the experiment. Note that all stimuli were developed in or translated into (e.g., from Pecher et al., 2003) the French language, and all participants were Francophone.

2.3. Procedure

Participants were tested in sessions of up to 9 students in a computer room. Stimuli were presented by E-Prime 1.1.4.1 on PCs with Processor IntelPentium 2.3 GHz / 256 Mb SDRAM computer with a 17-inch color monitor. Participants were seated in front of the monitor and invited to read the instructions that appeared on the screen. Instructions stated that participants were to decide as quickly and accurately as possible whether a property was usually true for the concept. Instructions also emphasized that "the property should be considered true if it is USUALLY a part of the concept's definition, that is, that the property is USUALLY used to describe or to define the concept. Inversely, properties that are ONLY semantically associated with the concept should be considered as false". Some examples were provided to illustrate (e.g., SCISSORS "can be" cut; false).

Each trial started with a fixation stimulus (*****) presented for 500 ms and replaced by three vertically aligned lines of text composing the to-be-evaluated item. The first line contained the concept word in uppercase, the second line contained the words "can be" (i.e., in French "peut être") and the third line contained the property in lower case. Each line was printed in Arial Bold 20 and separated from next by an empty line. The three lines of text appeared simultaneously and remained on the screen until the participant made a "true" ("L" key) or a "false" ("S" key) judgement on an AZERTY keyboard. In order to avoid influences on the processing of emotion concepts, we provided participants with no performance feedback. The next trial started 300 ms after the response was given. The experiment was divided into 6 different blocks each separated by a fixed rest period of 30 seconds followed by a "get ready period" that the participants could terminate if they were ready to work again. The experiment lasted about 20 minutes.

3. Results

Response times (RTs) on target trials for which participants responded accurately to both the context trial and the target trial were retained for analysis. RTs were also cleaned for outliers following standard deviations cutoffs (i.e., two standard deviations in the present study) as proposed by Ratcliff (1993). The percentage of valid data was high in each of the condition and skewness of RTs was low (Table 2). Analyses were computed also on accuracy. Analyses allowed comparisons of RT and accuracy on target trials that were preceded by the same-modality context trials as compared to the different-modality context trails. This was done for each of the three valences.

We first ran a 3 (Target valence: neutral, positive, negative) × 2 (Context: different, same) MANOVA. RTs for targets preceded by other modality context trials were slower ($M = 1362$ ms; $SE = 24$) than RTs for targets preceded by same modality context trials ($M = 1261$ ms; $SE =$

Table 2
Mean error rate, percentage of valid response time values, and skewness of response times, as a function of the context, the valence, and the modality type

Context	Valence	Modality type	Mean Error Rate on Target Trials (*SD*)	Percentage of Trials Remaining for Analysis	Skewness of Response Times
Same	Neutral	Sensory	.11 (.12)	73	0.62
	Positive	Sensory	.06 (.09)	83	1.13
		Affective	.03 (.08)	69	1.28
	Negative	Sensory	.12 (.13)	64	0.38
		Affective	.06 (.11)	79	1.00
Different	Neutral	Sensory	.08 (.10)	68	0.44
	Positive	Sensory	.15 (.10)	72	0.58
		Affective	.09 (.13)	79	0.85
	Negative	Sensory	.11 (.17)	73	0.63
		Affective	.18 (.25)	68	0.22

21), $F(1, 80) = 77.52$, $p < .001$, indicating a switching (modality) cost. There was also a main effect of valence, $F(2, 79) = 43.69$, $p < .001$, such that responses were faster on positive trials ($M = 1234$ ms) than on neutral trials ($M = 1330$ ms), and responses were faster on neutral than negative trials ($M = 1370$ ms). Although switching costs were smaller on neutral trials ($M = 78$ ms) than on positive trials ($M = 109$ ms) and on negative trials ($M = 116$ ms), the relevant interaction was not significant, $F(2, 79) < 1$, ns.

Similarly, analysis of accuracy revealed a main effect of Context (Accuracy Different < Accuracy Same), $F(1, 80) = 15.87$, $p < .001$ and a main effect of Valence (Negative < Positive), $F(2, 79) = 4.66$, $p = .01$. Moreover, the interaction between Context and Valence was significant, $F(2, 79) = 17.86$, $p < .001$. This interaction reveals that the context effect (i.e., switching cost) was smaller on neutral trials ($M = 2.8$ %) than on positive trials ($M = 7.8$ %) and on negative trials ($M = 5.5$ %).

In order to detect differences in processing negative and positive stimuli, we next conducted a 2 (Target valence: positive, negative) × 2 (Context: different, same) × 2 (Modality: sensory, affective) MANOVA. RTs for targets preceded by other modality context trials were slower ($M = 1350$ ms; $SE = 26$) than RTs for targets preceded by the same modality context trials ($M = 1240$ ms; $SE = 22$), $F(1, 74) = 64.83$, $p < .001$. This was also true for accuracy, $F(1, 80) = 41.95$, $p < .001$. There was also a main effect of valence for RT, $F(1, 74) = 72.04$, $p < .001$ and for accuracy, $F(1, 80) = 9.12$, $p < .01$. Although RTs were slower for the affective modality ($M = 1286$ ms; $SE = 23$) than for sensory modalities ($M = 1304$ ms; $SE = 24$), the main effect of Modality was not significant, $F(1, 74) = 2.02$, $p > .10$. This was true for accuracy as well, $F(1, 80) = 2.59$, $p > .10$. As Table 3 shows, switching modality costs were present for the three valences and for the emotional concepts for the two systems (sensory and affective).

Analysis of RTs revealed a significant interaction between valence and modality, $F(1, 74) = 4.57$, $p < .05$. This interaction was due to a larger valence effect when modalities were sensory (positive: $M = 1200$ ms, $SE = 24$; negative: $M = 1372$ ms, $SE = 28$) than when they were processed in the affective system (positive: $M = 1251$ ms, $SE = 28$; negative: $M = 1358$ ms, $SE = 27$). The same valence by modality interaction was also significant in the analysis of accuracy, $F(1, 80) = 6.38$, $p = .01$. Importantly, there was also a significant modality by context interaction the in RT analysis, $F(1, 74) = 6.49$, $p = .01$ and in the Accuracy analysis, $F(1,80) = 7.28$, $p < .01$. This interaction is explained by a smaller effect of context (i.e., switching cost) for sensory (RTs : Different $M = 1324$ ms vs. Same $M = 1248$ ms; Accuracy : Different $M = .874$ vs. Same $M = .912$) than for affective modalities (RTs : Different $M = 1376$ ms vs. Same $M = 1232$ ms; Accuracy : Different $M = .863$ vs. Same $M = .958$).

4. Discussion

According to several recent theories, sensorimotor simulations constitute conceptual content. Put differently, in this view, the representation of a concept involves running a simulation of past experience with that concept by reactivating, at least partially, neural states that occurred during prior experience with the concept in specific situations. In support of this idea, findings from recent research have demonstrated that considering a property of a concept rep-

Table 3
Mean response times in milliseconds (standard errors) and Paired *t* test comparisons for verifying properties on target trials as a function of Valence of targets (Neutral vs. Positive vs. Negative), Target modalities (Sensorial vs. Affective) and Modality Context (Different vs. Same)

	Sensorial Modalities[a]					Affective Modality[a]				
	Different[b]	Same[b]	Switching Cost	*t* Test	p	Different	Same	Switching Cost	*t* Test	p
Neutral	1369 ms (28.1)	1291 ms (24.2)	78 ms	2.96	< .01	—	—	—	—	—
Positive	1250 ms (24.7)	1162 ms (23.6)	88 ms	4.93	< .001	1328 ms (31.9)	1197 ms (27.9)	131 ms	4.38	< .001
Negative	1411 ms (32.5)	1336 ms (27.7)	75 ms	2.65	< .01	1440 ms (33.6)	1275 ms (30.1)	165 ms	4.67	< .001

Note. Standard errors are presented in parentheses.
[a]Sensorial vs. Affective modalities refer to the modality of the Target's property. [b]Different and Same are related to the modality of the context trials which just preceded the presentation of the target trials.

resented in one modality slows down the processing of a subsequent property that is represented in a different rather than same modality (Pecher et al., 2003, 2004).

In the present study, similar switching costs occurred both for neutral concepts, replicating Pecher and colleague's work, and for affective concepts and their affective properties. And, for affective concepts, similar costs were incurred whether switching involved sensorial modalities or the affective system. The findings therefore support the novel hypothesis that the judgment that a *FRIEND* can be *tender* or a *COUPLE* can be *happy* involves a simulation of this potential property in the affective system. Such an empirical finding is predicted by Barsalou (1999) who proposed that abstract concepts could be heavily based on introspective experience such as emotional states.

One interesting interaction, not *a priori* expected, was also observed. It involved valence and modality, and indicated a larger valence effect (i.e., properties of positive concepts were verified more quickly and more accurately than properties of negative concepts) for properties verified in sensory modalities than in the affective system. In other words, the verification of features of positive concepts were faster than negative, and especially so if the features to be verified were visual or auditory. This is probably not surprising. The processing of positive information is typically significantly faster than the processing of negative information (e.g., Niedenthal, Halberstadt, & Setterlund, 1997). Furthermore, negative information tends to attract and hold attention (e.g., Öhman, Lundqvist, & Esteves, 2001). Therefore, verification of affective features of affective concepts should show a valence effect; this is a typically processing effect. However, if attention is captured by negative information then the verification of non-affective features will be even slower because the attention to the negative features inhibits the processing of emotion-unrelated features.

Alternative explanations of our results can be entertained. Even if these results are not *a priori* predicted by amodal theories, they could be nevertheless explained *a posteriori* by amodal frameworks. From an amodal point of view, for instance, concepts and properties are stored within a single, general system. It is therefore possible that properties from one modality are more strongly associated with each other. In such a way, they could prime one other in a sequential design. However, prior evidence argues against this interpretation. First, Pecher et al. (2003, Experiment 2) demonstrated the absence of effect of associative strength of properties from the same modality whereas switching modality costs remain significant. Second, the priming literature shows that semantic and lexical priming produced by an item dissipates very quickly after processing. For instance, the affective priming literature shows that a Stimulus Onset Asynchrony (SOA) of 300 ms is located at the edge of the activation curve of the prime (Glenberg & Kaschak, 2002, see also Klauer, 1998). In the present study there were more than 2000 ms separating presentation of the context property and the target property. It is thus unlikely that switching costs were due to associative priming.

The present research joins a number of recent studies that link simulation in the affective system to the processing of emotional information. One line of related studies indicates that the imitation of emotional expression is an important mechanism underlying the recognition of facial expression of emotion (Adolphs & Tranel, 2003; Niedenthal, Brauer, Halbsterstadt, & Innes-Ker, 2001) and the understanding of the emotional state of the other (e.g. Decety & Jackson, 2004; Gallese, 2003; Wicker, Keysers, Plailly, Royet, Gallese and Rizzolatti, 2003). Other work shows that the inhibition of motor movements related to emotion impairs the processing of emotional words and sentences (e.g., Neumann & Strack, 2000). Such studies all support the utility of the present approach in the modelling of information processing. However, it should be noted that whereas prior studies are suggestive, none tests an embodied simulation approach to emotion concepts, and none examines the simulation of concepts in other sensory or motor systems as well as the affective system in the same experimental task.

Although future studies can be easily imagined, the present results are consistent with the notion that concepts are not only grounded in perception and action, but also importantly in affective (introspective) experience. Thinking about taking an airplane to a desired vacation destination involves partial simulations in the visual and other sensory systems. But it also involves a (potentially frightening, or, alternatively, exhilarating) simulation in the affective system. Further work will have to explore the specifics of this simulation. Recent advances in cognitive neuroscience will allow precise hypothesis to be tested about the neural bases of such simulations.

Acknowledgments

This study was supported by a FSR post-doctoral grant from the catholic University of Louvain to Nicolas Vermeulen and by Grant 1.5.175.06 from the Belgian National Fund for Scientific Research to Olivier Luminet.

Nicolas Vermeulen is a Postdoctoral Researcher at the National Fund for Scientific Research, Belgium. Olivier Luminet is research associate at the National Fund for Scientific Research, Belgium. The research was conducted while Nicolas Vermeulen was in a Postdoctoral stay at Blaise Pascal University of Clermont-Ferrand, France.

Authors want to thank Diane Pecher and colleagues for providing the material used in their 2003 study and also Gordy Pleyers and Céline Corman for their help in collecting data.

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