Acta Psychologica 129 (2008) 108–111

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Activation and integration of motor components in a short-term priming paradigm

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ARTICLE INFO

Article history:
Received 23 October 2007
Received in revised form 28 April 2008
Accepted 29 April 2008
Available online 24 June 2008

PsycINFO classification:
2343

Keywords:
Activation and integration
Gesture priming
Knowledge emergence

ABSTRACT

The aim of the present research was to study the processes involved in knowledge emergence. In a short-term priming paradigm, participants had to categorize pictures of objects as either "kitchen objects" or "do-it-yourself tools". The primes and targets represented objects belonging to either the same semantic category or different categories (object category similarity), and their use involved gestures that were either similar or very different (gesture similarity). The condition with a SOA of 100 ms revealed additive effects of motor similarity and object category similarity, whereas another condition with a SOA of 300 ms showed an interaction between motor and category similarity. These results were interpreted in terms of the activation and integration processes involved in the emergence of mental representations.

1. Introduction

Cognitive psychology has long considered the information we keep in memory to be purely abstract or amodal. However, it now appears that the opposite is true. Many experiments conducted in the fields of both cognitive psychology and neuroscience have shown that the conceptual knowledge we call upon in any activity requires the activation of neuronal systems typically associated with perceptuo-motor mechanisms (for reviews, see Barsalou,1999, 2005a, 2005b; Martin & Chao, 2001; Martin, Ungerleider, & Haxby, 2000; Slotnick, 2004; Versace, Labeye, Badard, & Rose, in press; Zwaan, Stanfield, & Yaxley 2002). For example, Tucker and Ellis (1998) asked their participants to categorize images of objects according to their orientation (presented normally or inverted). The results revealed shorter response times for objects when the hand used to answer was the same as the hand thought to be used to grasp this object. More recently, Myung, Blumstein, and Sedivy (2006) investigated motor-based functional knowledge of man-made objects. In their experiment, participants had to make a decision about a target word following a prime that was either related (shared manipulation features) or unrelated. Decisions were significantly faster when the prime and target shared manipulated features.

These studies clearly demonstrate that the mental representation of the object necessary for its categorization includes motor components of the actions that may potentially be performed with regard to the object. In more general terms, apprehension of an object requires the parallel activation of sensory, motor and other components. However, such activation alone cannot account for the coherence and unicity of the knowledge stemming from the object. Given that multiple areas of the brain are systematically involved in any specific cognitive operation, the integration (and synchronization) of activities between these zones therefore appears essential. The importance of activation and integration mechanisms for the emergence of knowledge has already been evoked in literature. For example, Stoet and Hommel (1999), Stoet and Hommel (2002); see also Huang, Holocombe, & Pashler, 2004) found evidence that action planning is affected by perceptual feature integration and proposed that binding mechanisms allow for the emergence of coherent representations from initial representations distributed throughout the brain. In 1999, they investigated how a previously prepared action plan residing in memory for later execution influences the preparation of another action plan. They found that if the second plan shares an action feature with the first, planning takes longer. In the same vein, in 2002 the authors asked subjects to memorize features such as the position (left or right), shape, and color of a stimulus A, for latter recall. Stimulus A was presented 1000 ms following by a mask for 1000 ms, or for 100 ms without a mask. Stimulus B was then presented and required a fast manual response with the left or right index finger. The results show that with a long SOA, responses are initiated more slowly if the response location corresponds to the location of the previously memorized stimulus. However, with a short SOA, when the stimuli were presented in close succession, positive effects were obtained. For the authors, perceptual feature

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doi:10.1016/j.actpsy.2008.04.010

integration allows for the construction of a perceptual object representation that occupies the "codes" of the object features so that these codes are temporarily less available for the construction of other (the action's representation). This integration is a time-consuming process that can be distinguished from the mere activation of feature codes. Interestingly, the authors obtained the same results with a long SOA when the experiment required no memorizing of stimulus A: Stimulus A served as a Go-signal for task B; its features had no behavioral relevance. Thus, "responses to stimulus B were significantly slower in the overlap than in the no-overlap condition, and this binding effect cannot be attributed to memory rehearsal or any other strategies" (for a theoretical development of these works, see, Hommel, 2004).

2. The present study

The aim of the present study was first to provide further evidence of the perceptual nature of knowledge. The second objective was to study the dynamics of features activation and integration of a stimulus more closely by using a short-term priming paradigm in which the SOA between the prime and the target was manipulated. Versace et al. (in press) developed the idea that multimodal activation and integration mechanisms may account for the emergence of knowledge. They assumed that exposure to the environment translates very rapidly into numerous structures which encode sensory dimensions by means of parallel activations. These initial activations then spread very quickly to other components, which are related to the other (sensori-motor and emotional) properties of the environment. These multidimensional activations may influence processing occurring very soon after the appearance of the inducing object. These initial multimodal activations, specific to the elementary properties of objects, are necessarily integrated gradually and more thoroughly at the intra-modal and intermodal levels. Such integration makes it possible to access increasingly elaborate and unitary knowledge about the current environment. However, multi-level integration such as this is thought to require more time than the initial multimodal activation. Consequently, the manipulation of the SOA between the prime and the target in a short-term priming paradigm should allow these two stages of knowledge emergence to be dissociated.

Our priming paradigm involved a task where pictures of objects had to be categorized semantically into "kitchen objects" or "do-it-yourself tools". The primes and targets represented objects in either the same semantic category or different semantic categories (same object category vs. different object category), and their use involved gestures that were either similar or very different (similar gesture vs. dissimilar gesture). We expect objects to have similar gestures if their intended usage requires that they be manipulated in the same manner. The motor relationship between the prime and the target pairs was therefore based on manipulation features shared between objects (Myung et al., 2006).

For one group of subjects, the prime appeared for 100 ms and the target was presented immediately afterwards. According to Stoet and Hommel's experiment (2002), we assumed that exposure to the 100 ms prime would be sufficient to permit activation of its components (motor components, for example) but not their integration. Each component would therefore be activated independently and would act in an autonomous manner. We consequently predicted additive facilitatory effects of (a) the similarity between the motor components of the prime and the target, and (b) the similarity between the prime and target object categories.

For another group of subjects, the prime was presented for 300 ms, a period expected to allow the integration in an unitary trace of prime components, the motor component as well as other components, probably shared by objects of the same object category. Therefore, a priming effect should be observed only if the integrated trace resulting from prime presentation shares a maximum of elementary components with the target, ie only when they belong to the same category and involve similar motor components. If the prime and target involve very different gestures or belong to different object categories, the mismatch between the integrated prime and the target is too great for the influence of a single element to manifest itself. In that case, the expression of a feature depends on the expression of other ones. The facilitatory effect of motor similarity should only be expressed if the objects are in the same category. Similarly, the facilitatory effect of category similarity should only be expressed if the objects involve similar motor components.

3. Experiment

3.1. Method

3.1.1. Participants

Eighty right-handed students from the Lumière Lyon 2 University, France, were tested. All of them volunteered for the experiment and had eyesight that was either normal or corrected-to-normal.

3.1.2. Material

The experimental material consisted of 50 photographs of objects. 25 of them were pictures of DIY tools while the other 25 represented kitchen utensils (for the complete list of stimuli, see E. Labeye personal page: http://recherche.univ-lyon2.fr/emc/113-Elodie-Labeye.html). Objects were straightforward and ordinary. Their familiarity and complexity were controlled. The size of the photos was 370 pixels by 265 pixels, and the objects were pictured against a white background. 10 of the 50 photos were selected as target pictures, i.e. five for each category. Each of the 10 targets was then associated with four prime pictures selected according to category ("kitchen" or "DIY") and the gesture required for normal use of each object. For each target, two of the prime pictures selected represented an object of the same category, involving a gesture either relatively similar to, or very different from that involved in respect of the target object. The other two prime pictures represented an object from the other category, again involving a gesture very similar to, or very different from that involved in respect of the target object.

3.1.3. Design and procedure

The experiment was carried out on a Macintosh microcomputer (eMac G4). Psyscope software (Cohen, McWhinney, Flatt, & Provost, 1993) was used to create and manage the experiment. In addition, a chin rest was used so that the distance between the subjects and the monitor remained constant (60 cm).

After filling in a consent form, each subject was tested individually during a session lasting approximately 10 min. We explained to the subjects that they would be taking part in an experiment where they would be shown pairs of pictures. Their task was to judge as quickly and accurately as possible whether the second picture represented a kitchen utensil or DIY tool and to give their answers by pressing the appropriate keys on the computer keyboard. They used their right hand to press the "DIY" key and their left hand to press the "kitchen" key (and vice-versa for half of the subjects). As soon as they responded another picture was displayed followed by the picture they were required to categorize.

Two groups were tested with two different SOA. At the start of each trial a fixation point was displayed for 1000 ms in the middle of the computer screen. A prime was then displayed for 100 or 300 ms depending on the group (40 subjects in each group). The target appeared when the prime was removed and remained on the screen until the subject responded. All the stimuli were displayed in the middle of the screen, with an intertrial interval of 1000 ms.

Each participant saw three blocks of 40 trials each. In each block, 10 targets were repeated in each of the four experimental conditions: prime in same object category associated with similar gesture, prime in same object category associated with dissimilar gesture, prime in different object category associated with similar gesture, and prime in different object category associated with dissimilar gesture. The order of the items in the blocks was random, and the item order was reversed for half of the participants.

3.2. Results and discussion

The mean correct responses latencies and error rates were calculated across subjects for each experimental condition. Latencies below 100 ms or above 1200 ms were removed (less than 3% of data). Separate repeated measures analyses of variance were performed on latencies and error rates with subjects as random variables, and gesture similarity (prime and target involving similar versus dissimilar gesture) and object category similarity (prime and target in same category or different categories) as within-subject factors, and SOA (100 ms or 300 ms) as between-subjects factor.

Error rates analyses revealed no main effects of "gesture similarity", "object category similarity" or "SOA", and no interaction between these factors. Latencies analyses revealed main effects of "gesture similarity", $F(1,78) = 6.1$, $p < 0.05$, and "object category similarity", $F(1,78) = 29.27$, $p < 0.01$. Globally, categorization was faster when the prime and the target involved a similar gesture than when they involved dissimilar gestures, and when prime and target were in the same object category rather than different object categories. More importantly, a significant interaction was obtained between "gesture similarity", "object category similarity", and "SOA" ($F(1,78) = 8.98$, $p < 0.01$). This interaction is illustrated in Fig. 1. To explain it, separate analyses of variance were performed for each SOA.

Analysis showed that with a SOA of 100 ms correct latencies were significantly shorter when prime and target were associated with a similar gesture (630 ms) than when they were associated with dissimilar gestures (637 ms), $F(1,39) = 3.96$, $p = 0.054$. Analysis also showed that correct responses were significantly shorter when the prime and the target belonged to the same semantic object category (623 ms) than when they belonged to different semantic object categories (644 ms), $F(1,39) = 28.08$, $p < 0.05$. Finally, the interaction between "gesture similarity" and "object category similarity" was not significant.

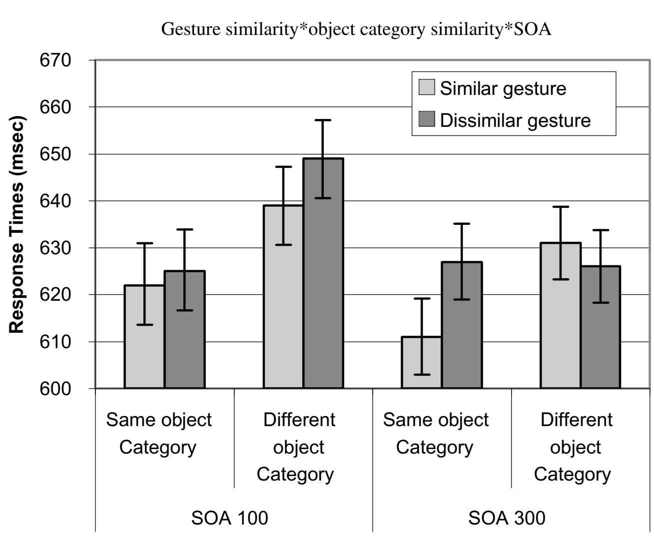

Fig. 1. Mean response latencies (RTs), as a function of gesture similarity, object category similarity and SOA.

These results support our hypothesis that the emergence of knowledge includes a stage in which not only the motor components but also other sensory components are activated, with the expression of each of these being independent.

With a SOA of 300 ms, latencies analysis revealed a significant main effect of object category similarity (619 ms when prime and target were in the same semantic object category, and 628 ms when they were in different semantic object categories, $F(1,39) = 5.45$, $p < 0.05$), and a significant interaction between "gesture similarity" and "object category similarity" ($F(1,39) = 7.76$, $p < 0.05$). Planned comparisons showed a significant effect of "gesture similarity" only when the prime and the target were in the same object category ($F(1,39) = 8.82$, $p < 0.01$) and a significant effect of "object category similarity" only when they were associated with a similar gesture ($F(1,39) = 13.86$, $p < 0.01$).

These results confirm our hypothesis: when the SOA allow the integration of prime components, the facilitatory effect of motor similarity is expressed only if the objects are in the same category. Similarly, the facilitatory effect of category similarity is expressed only if the objects involve similar motor components. Priming effects are observed only if the integrated prime "representation" has a maximum of elementary components in common with the target.

4. General discussion

The experiment reported in this paper supports the idea that the knowledge we possess of objects in our environment is composed, *inter alia*, of motor components which are the result of the many interactions we have had with these objects. With a 100 ms SOA, priming effects are observed when use of a prime object and a target object involves a similar gesture. However, the results also show that, with a 100 ms SOA, even if the prime and the target did not involve similar motor components, target processing was facilitated if the prime belonged to the same category. These results show that when the first object is presented its mental representation is activated and, if this representation bears any similarity to the representation activated by the second object, processing of the latter will be more effective. In this case, similarity relates to both motory utilization of the objects and a number of other components when the two objects belong to the same semantic category.

However, results also showed that priming effects vary as a function of time. When the prime was presented for 300 ms rather than 100 ms, facilitated processing of the target was no longer possible on the basis of gesture similarity or category similarity alone. Priming effects were observed only when the prime and the target were in the same category and involved similar motor components.

The explanation for our results is based on Versace et al.'s (in press) assumptions that exposure to an object very rapidly activates numerous structures which encode its sensori-motor dimensions. These initial multidimensional activations may influence processing occurring very soon after the appearance of the object. However, they are then integrated gradually at the intra-modal and intermodal levels. Such integration makes it possible to access increasingly elaborate and increasingly unitary knowledge about the current environment but is thought to require more time than the initial multimodal activations. That is why, with 300 ms SOA, priming effects were observed only when the integrated prime "representation" had a maximum of elementary components in common with the target. The integrated nature of the representation explains why each prime component did not act independently, as manifested statistically in the form of an interaction. Some may argue that activation effects related to gesture similarity could also be the result of visual similarity between the prime and the target. Objects that had a given gripping gesture in common also shared visual features. Nevertheless, even if both visual and motor components could be responsible for a priming effect in the similar gesture condition, this bias cannot explain the change in priming effect with prime duration. This change as a function of SOA highlights the dynamics of knowledge emergence, stemming from multimodal activation and integration.

Our results could also be interpreted according to Hommel's (2004); see also Kahneman, Treisman, & Gibbs, 1992) notion of "object file". Hommel explains the influence of binding in perception on action planning by the creation of "event file" by a single co-occurrence of the bound features. For him, each encounter with a perceived event or to-be-produced event, such as an intentional action, "leads to the creation of a transient, episodic 'event file' – a network of bindings that temporarily links codes of the relevant or salient features of the perceptual event, accompanying action, and task context. During the lifetime of an event file another encounter with one or more of the bound features triggers the automatic retrieval of a larger part of a sort of pattern-completion process that might hamper the creation of new event files for features-overlapping but non-identical events".

So, according to Hommel's theory[1], when the prime and the target belong to the same object category, the previously created prime "event file" is reactivated when the target is viewed. When the motor component mismatches in this event file, performance is significantly hampered. When the prime and the target belong to a different tool category however, the prime "event file" may not even be sufficiently reactivated (because of the lack of a sufficient match), and so there is no significant effect. The same explanation applies to the significant effect of "category similarity" only when the prime and the target were associated with a similar gesture: when they involve a similar gesture, the previously created prime "event file" is reactivated when the target is viewed. When several sensori-motor components mismatch, performance is hampered. When the prime and the target involve dissimilar gestures, however, the prime "event file" may not be sufficiently reactivated (the motor components are definitely among the most important components for objects), and so there is no significant effect.

If this explanation is correct, it means that with a 100 ms SOA, the prime "event file" did not have enough time to construct. In this condition, a priming effect only comes from the initial multimodal activation of the sensori-motor components of the prime.

However, the explanation based on Hommel's theory is not incompatible with that based on Versace et al.'s model. In fact, the most important implications of our study concern, first, the high level of involvement of the sensori-motor areas in the emergence of knowledge, and second, the dynamics of this emergence, which clearly involves different stages resulting from multidimensional activation and integration mechanisms.

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[1] Our thanks go to Ed Symes for suggesting this explanation to us in his review of this paper.