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The Sensory Nature of Knowledge

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Abstract

The aims of the present studies are to assess the sensory nature hypothesis of knowledge through a series of experimental results. Especially, we investigated the links between memory and perception using a short-term priming paradigm based on a previous learning phase consisting of the association between a geometrical shape and a white noise. Consequently, the priming phase examined the effect of a geometrical shape, seen in the learning phase, on the processing of a target (tones or picture). Our main results demonstrate that memory and perception share some mechanisms and at least components. These ones are involved for the processing of each form of knowledge (i. e., episodic and semantic). At last, reflections about the implication of this work to study perceptual learning and memory are presented.

Keywords: Perception, Integration, Multisensory Memory

1 Introduction

How do people represent information in memory? What is the nature of the information stored in memory? We can consider that learning representations or concepts depends on upon perceptual experiences. In that view, the comprehension of the relation between memory (*i. e.*, concepts) and perception *(i. e.*, percepts) is critical. Classicaly, perception and memory are vertically describded. In that case, perception extracts perceptual units from the environment thanks to *bottom-up* processes. These units are then converted into representations and are stored into memory. In return, the activation of these representations can influence the perception thanks to *top-down* processes. In that conception, the differences between memory and perception are both structural and functional (*e. g.*, Humphreys & Riddoch, 1987). Regarding the structural distinction, recent neuroimaging studies suggest that both memory and perception share common brain areas (for a review, see Versace, Labeye, Badard & Rose, 2009). For instance, Martin and collaborators (2000) showed that conceptual processes (i. e., word-object naming) and perceptual processes (*i. e.*, picture-object naming) involve the same brain area, depending on the perceptual (*i. e.*, color) and motor properties of the objects. Regarding the functional distinction, recent neuroimagering researches also suggest that the neural structures of long-term memory are involved during the perception of objects or events (see Murray & Bussey, 2007). In particular, the medial temporal lobe cortex ensures the integration of the different components of objects by means of a hierarchical integration mechanism. Recently, Shimamura and Wickens (2009) have provided evidence in support of the idea that memory activities (*e. g.*, single item recognition) might be underpinned by this integration mechanism

In this paper, we aim at developing a conception in which perception and memory are at the same functional level in cognitive architecture. In other words we want to bring experimental evidence that perception and memory act simultaneously on the same processing units. The only difference is that perception involves perceptually present units whereas memory involves reactivation or simulation of these units. Seeking this purpose, we have to provide evidence that 1) memory is able to keep traces from perceptual events; 2) memory and perception use the same processing units.

2 The perception leaves memory traces

In the daily life, the organism treats essentially multisensory signals. The unified perception of a multisensory environment requires not only multiple activations in the sensory areas but also the synchronization and the integration of these activations (*e. g.*, King, 2005). The existence of multisensory integration is particularly well illustrated by the McGurk effect (McGurk & Mac Donald, 1976). This effect reveals that subjects tend to perceive /da/ when they see the syllable /ga/ and hear the sound /ba/. This demonstrates the ability of a sensory system to modify the processing of another sensory system. Integration could be described as the capacity of the perceptual system to process more efficiently (or differently in case of McGurk effect) a multisensory stimulus than the sum of these two parts. Number of neurosciences studies was dedicated to the study of the multisensory integration between vision and audition. For example, King and Calvert (2001) have shown that some neurons in the superior colliculus are more highly activated by multisensory than by unisensory stimuli. Similarly, electrophysiological studies have provided some evidences of audiovisual integrations (between a shape and a tone) that occur in the visual cortex after a period of just 40 ms (Giard & Perronet, 1999). In the same vein, authors have shown that spatial congruity enhances audio-visual integration (Teder-Sälejärvi, Di Russo, McDonald, & Hillyard, 2001). At last, the role of attention during perception of a multisensory event and its consecutive integration is not well established (see Fort & Giard, 2002).

If a visual stimulus and an auditory stimulus tend to be integrated during a perceptual activity (e. g., perceptual categorization or discrimination), is it possible that memory could capture this integration? Once perceived, the perceptual properties of a multisensory object can be preserved in memory in the form of a memory trace. This is due to an integration mechanism that allows for the creation of durable links between perceptual properties within the same memory representation (see Brunel, Labeye, Lesourd & Versace, 2009; Hommel, 1998; Labeye, Oker, Badard, & Versace, 2008). Contrary to simple associative learning (see Hall, 1991), once features are integrated within an exemplar, it is difficult to access the individual features (see Labeye et al., 2008; Richter & Zwaan, 2010). This new unit, once acquired, becomes a functional "building block" for subsequent processing and learning (in language, Richter & Zwaan, 2010; in memory, Labeye et al., 2008; or attention, Delvenne, Cleeremans, & Laloyaux, 2009). In this view, the integration mechanism is a fundamental mechanism of perceptual learning (see the unitization mechanism, Goldstone, 2000) or contingency learning (see Schmidt & De Houwer, 2012; Schmidt, De Houwer, & Besner, 2010). From this idea we can make the prediction that once two features have become integrated, the presence of one feature automatically suggests the presence of the other. Thus, if the simultaneously presentation of an auditory information (a sound) and a visual information (a shape) leads to the creation of a multisensory memory trace, then we can easily predict that the visual component presented alone, as a prime, should influence the perception of a sound targets. We examined this prediction through an original paradigm divided in two phases. First, a learning phase (consisting in a shape categorization task) in which we manipulated the association between a given geometrical shape and a white noise[1]. As a consequence, participants simply had to categorize a shape as a square or a circle (each shape was presented in differents shades of gray). It is important to stress that each shape was presented during 500 ms. One of this shape was systematically associated with a white noise (presented simultaneously dur-

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[1] A white noise is a random signal with a flat power spectral density. White noise is considered analogous to white light which contains all frequencies.

ing 500 ms), the other not. Then, a priming phase (see Figure 1) in which participants watched the geometrical shapes from the learning (as prime) and listened pure tones (as target). In this phase, participants had to discriminate the target into high-pitched or low-pitched. Our first result was a selective priming effect of the geometrical shape seen in the learning phase with a sound on the processing of targets tones.

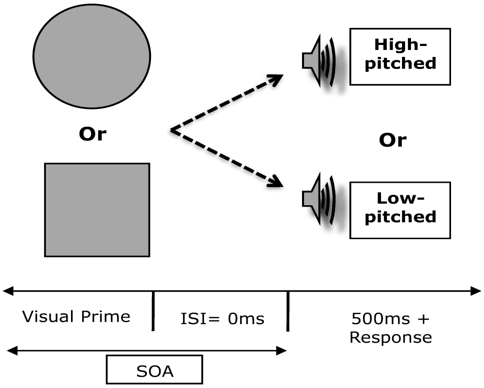


Figure 1: Organization of the priming phase. A prime shape (seen in learning phase), presented at different level SOA (100 ms or 500 ms), is immediately followed by a target tones that participants had to categorize in low or high-pitched sounds. Notes. SOA: stimulus-onset-asynchrony; ISI: Interval-Inter-Stimuli

This priming effect could be interpreted as an evidence of multisensory memory integration during perceptual learning. Indeed, when participants saw a shape that was previously presented with sound, it automatically reactivated the auditory memory component associated (see also Meyer, Baumann, Marchina & Jancke, 2007) that is able to influence the processing of targets tones. However considering only this result gave us any hint about the nature of the auditory memory component. Indeed, if memory and perception share the same processing units, then each component of the memory trace should be perceptual in nature even when they are reactivated. In order to test this assumption we manipulated the SOA during the priming phase. More specifically we predicted that reactivation of the sound should interfere with tone target processing if only if the SOA between the visual prime and the tone target is shorter than the duration of the sound associated with the shape during the learning phase. In this case, the interference effect would follow from temporal overlapping between previously associated sound reactivation and tone processing. A second and quite opposite prediction followed from different temporal constraints. Indeed, reactivation of the sound (by the visual prime) was expected to facilitate tone processing but only for

SOAs equal or longer than the duration of the sound associated with the shape during the learning phase. In this later case, not any temporal overlap occurred between simulation of the learned associated sound and target-tone processing so that target-tone processing should take advantage from the auditory preactivation induced by the prime. Our results (see Figure 2) were totally in line with these predictions.

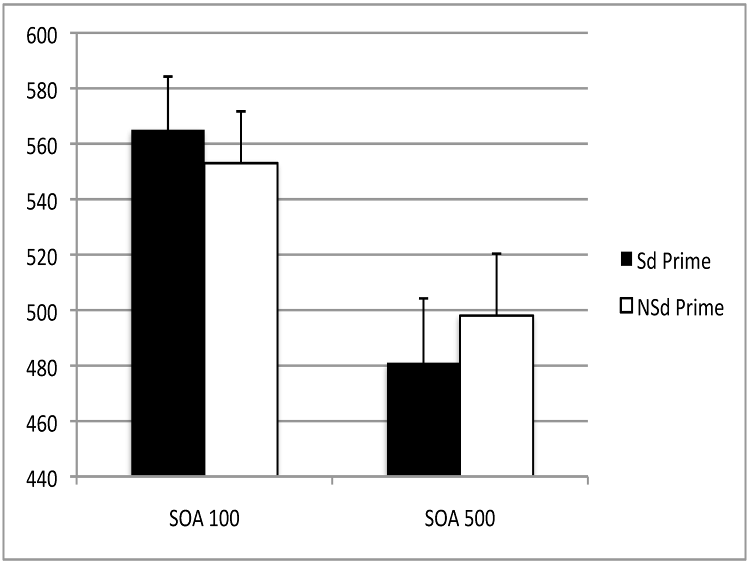


Figure 2: Interaction SOA*Prime type $F(1, 30) = 14.64$; $p < .001$. (a) For 100 ms SOA, significant principal effect of Prime type, $F(1, 15) = 5.25$; $p < .05$. (b) For 500 ms SOA, significant principal effect of Prime type, $F(1, 15) = 9.78$; $p < .01$. Results reproduced from Experiment 1 Brunel, Labeye *et al.*, 2009. Notes. Sd Prime: prime shapes that were presented with sound during learning phase; NSd Prime: prime shapes that were presented without sound. Errors bars represent standard errors.

We demonstrated that memory keep traces from perception thanks to an integration mechanism shared by perception and memory. As a consequence, the presentation of one component of a memory trace is able to reactivate the other components (which kept all of their encoded characteristics). Once reactivated, a compotenent is able to influence the ongoing process (see also Riou, Lesourd, Brunel & Versace, 2011). However, according to Nyberg et al. (2000), this kind of effect is limited to the processing of episodic knowledge and should not be observed when conceptual knowledge are at stake. Indeed, only episodic knowledge should keep some perceptual properties of former perceptual events. Such claim suggests the existence of modal and amodal forms of knowledge. The next section will be dedicated to this specific issue.

3 The Sensory Nature of Knowledge

What is the nature of our knowledge? Bring an answer to that question is not easy and suggests at least two differents perspectives. First, we could consider that each form of knowledge is qualitively different and as a consequence differs into their nature (i. e., modal vs. amodal). According to Tulving (1995), our knowledge could be viewed as semantic or episodic. These two sorts of knowledge depend on the existence of two independent memory systems. The semantic memory system is more likely to be involved in the processing of general amodal knowledge whereas the episodic memory system is involved in the processing of specific modal knowledge. Whereas Tulving argued that these two kinds of memory are dissociated and differ in the abstractness of the information they retain, increasing numbers of studies have demonstrated the existence of conceptual representations which nevertheless continue to possess a perceptual nature (Barsalou, 2005; Barsalou, 2008; Barsalou, Simmons, Barbey, & Wilson, 2003). Indeed, there is experimental evidence showing that the reactivation of perceptual or body states facilitates later conceptual processing for those concepts that share the same perceptual characteristics as the reactivated ones (see Pecher et al., 2004; Van dantzig et al., 2008). In that view, memory processes are deeply rooted in perceptual and action systems (see Barsalou, 2008) and, as consequence, access to all forms of knowledge is linked with automatic reactivation of perceptual or body states. In that context we can predict that conceptual processing involve automatic reactivation which is not limited to a given sensory memory component but should be observed for each diagnostic sensory component associated with a particular concept.

In order to test that prediction, we designed an experiment based on the same paradigm we described in the previous section. The learning phase is still consisting in learning an incident association between a geometrical shape and a white noise. The second phase consisted of a short-term priming paradigm (see Figure 4) in which a shape, either associated or not with a sound in the first phase, preceded an object-picture. The participants had to categorize this picture as representing either a large or a small object (more or less than 50 cm high). We manipulated the SOA as well as the nature of the object so that half of the objects were typically “noisy” objects (e. g., a blender) whereas the others were typically silent (e. g., a screwdriver). In order to perform the task, participants had to recognize the object and reactivate the actual size of the object. However, if this reactivation is not limited to the visual component and can spread to others diagnostic components (here auditory), we should observe the same pattern of priming effect as described in the previous section but limited to the typically "noisy" targets.

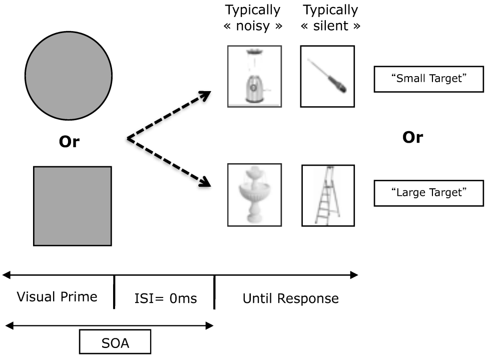
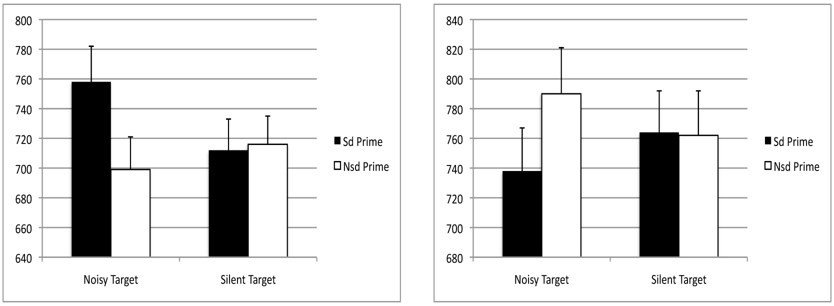


Figure 3: Organization of the priming phase. A prime shape (seen in learning phase), presented at different level SOA (100 ms or 500 ms), is immediately followed by a target picture that participants had to categorize in small or large target.

As depicted in Figure 4, we found a priming effect due to the reactivation of a memory auditory component by the visual sound prime (i. e., the shape seen with sound during the leraning phase) and limited to the "noisy" targets. As we expected, this effect was modulated by the SOA. Indeed, we found an interference effect with a SOA of 100 ms (Panel A) and a facilitation effect with a SOA of 500 ms (Panel B).



Panel A **Panel B**

Figure 4: **Panel A**: Interaction Prime type* Target type F $F(1, 15) = 10.6$;$p<.01$ (a) For Noisy target, significant principal effect of Prime type, $F(1, 15) = 10.6$, $p<.01$. (b) For Silent Target, $F<1$. **Panel B:** Interaction Prime type* Target type F $Fs(1, 15) = 6.24$; $p<.05$ (a) For Noisy target, significant principal effect of Prime type, $Fs(1,15) = 6.24$, $p<.05$. (b) For Silent Target, $F<1$. Results reproduced from experiment 1 Brunel *et al.*, 2010. Notes. Sd Prime: prime shapes that were presented with sound during learning phase; NSd Prime: prime shapes that were presented without sound. Errors bars represent standard errors.

We interpreted these results as evidence that the component reactivated by both the prime and the target has the same nature (*i. e.*, perceptual). Consequently, our results provide a strong argument in favor of the idea that access to conceptual knowledge is linked to the reactivation of the component dimension integrated within a concept (see Barsalou, 2008; Vallet, Brunel & Versace, 2010) which is consistent with a grounded view of cognition. In that case, we can consider that an opposition between modal and amodal form of knowledge is not appropriate for understanding phenomenological distinctions between forms of knowledge. This issue will be discussed in the next section.

4 Discussion

The aim of this paper was to propose experimental evidences in a favor of a horizontal view concerning the relation between memory and perception. In that view, perception and memory act simultaneously on the same processing units that are perceptual in nature. Indeed, our studies clearly show that the activation of an auditory memory component (a component that is not perceptually present) is able to influence the sensory processing of a sound or conceptual processing of a typically "sound" concept presented later. In that case, we have to consider that memory knowledge are necessarly sensory-based which is totally consistent with a grounded view of cognition (see Barsalou, 2008). So far we can say that: 1) memory keeps episodic traces from perceptual events; 2) memory traces integrate perceptual components; 3) the components of a given memory trace keep their perceptual caracteritics; 4) once a component is activated, this activation is able to spread to the others and influenced the ongoing processing irrespective the cognitive activity.

However there are remaining issues that we don't really address in that paper. The first concerns the type of processing units (*i. e.*, exemplars *vs.* features). Indeed, in the experiments reported here, participants have implicitly learned, through a simple categorization task, that a given shape, which varied through a separable dimension (*i. e.* brightness), is systematically presented with a sound and the other not. We interpreted the fact that only visual prime shapes (whatever the shape's brightness), which were presented with sound in the categorization task, influenced the target's processing (sound or picture of typical sound concepts) thanks to an "examplar based" memory view (Nosofsky, 1991; Logan, 2002). Each exemplar, which was associated with sound, reeactivate it previously encoded sound component. However, we can also interpret our results as an evidence of unitization (Goldstone, 1998) between a psychological feature, namely a geometrical shape (*i. e.* squares or circles) and an auditory feature (a white-sound). According to the unitization mechanism, we can say that the perfect co-occurrence of an auditory feature and visual psychological feature leads to the creation of a new functional feature combining these two features (Schyns, Goldstone & Thibaut, 1998).

In a recent works (Brunel, Vallet, Riou, & Versace, 2009; see also, Brunel, Goldstone, Vallet, Riou & Versace, 2013), we tried to experimentally settle between these conceptions of memory storage[2]. Basically, we used the same experimental design (learning phase followed by a priming phase with target tones) as Brunel, Labeye and collaborators (2009) experiment. Yet, we manipulated two imperfect rules of category learning sound-shape frequency association (High vs. Low) in learning phase (see Figure 5).

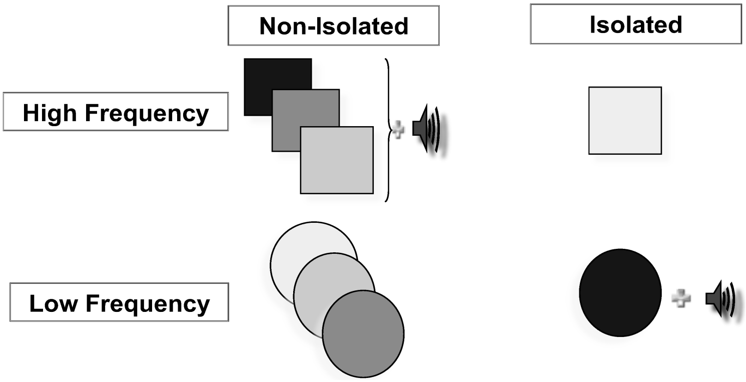


Figure 5: Stimuli used in Brunel, Vallet, Riou & Versace (2009) shape categorization task (learning phase). In this example, for the high frequency condition, three squares ("non-isolated") were presented simultaneously with a white noise, whereas one ("isolated") was presented without sound. Following the same example, in the low frequency condition, one circle ("isolated") was presented simultaneously with a white noise whereas the other three ones were presented alone ("non-isolated"). All the experimental conditions were counterbalanced between-subjects.

For the exemplars seen in High Frequency condition of learning, we observed a generalization effect in the priming phase. The isolated exemplar (which was presented without sound during learning phase) yields same priming effect than exemplars seen with sound in learning phase. So, generalization effect that we observed could be interpreted as a consequence of a multisensory unitization between a visual feature (shape)

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[2] According to Goldstone (1998) we refer here at « whole imprinting » and « feature imprinting ».

and an auditory feature (white-noise) that is an argument in favor of "feature imprinting" view of memory. Nevertheless, for the exemplars seen in low frequency condition of learning, we observed a discrimination effect in priming phase. The isolated exemplar presented with sound enhanced the processing of targets tones compared to the exemplars seen without sound during the learning phase. So, discrimination effect that we observed could be interpreted as a consequence of a multisensory integration between visual features (shape and level of brightness) and an auditory feature (white-noise) that is an argument in favor of "whole imprinting" view of memory. Taking together, these results suggest existence of multiple levels of representation (i. e., feature and exemplar, see Navarro & Lee, 2002), or multiple levels of processing (i. e., dimensional and featural), or both, during retrieval.

The second issue is related to the first one but concern the ability of the memory to produce qualitative and distinct forms of knowledge. We proposed that each form of knowledge emerges from the activation and the integration, and the synchronization of multiple memory traces (see also Versace et al., 2009). The difference between episodic and semantic is thus no more qualitative but rather quantitative, *i. e.* in term of number of episodes or traces, which are reactivated. We suggest that information is maintained in memory through a hierarchical multimodal memory integration mechanism. We consider that this mechanism, as presented in Figure 6, may be of relevance for the expression of the different forms of knowledge (*e. g.*, semantic and episodic) and the various types of memory processing (*i. e.*, categorization, recognition, memory retrieval).

In this model, an object is assumed to be perceived as a unified object because all its features are gradually integrated with one another. However, contrary to the exemplar-based approach, we suggest that what is stored in memory is the result of each integration at each level of LTM. We argue that a competition is involved during feature integration. This competition depends on both the distance between exemplar features within and between categories, and on the frequency of the presentation of the combinations of the different features.

In addition, we suggest that all the levels are not necessarily accessed for the processing of an exemplar in a given task: 1) to categorize an exemplar, it is sufficient to activate the unitized dimension which is relevant for the category; 2) to recognize an item, it is necessary to activate each unitized feature that is relevant for the exemplar.

In conclusion, we propose that each form of knowledge emerge from the dynamics interactions between multisensory units, which are both perceptual and mnesic in

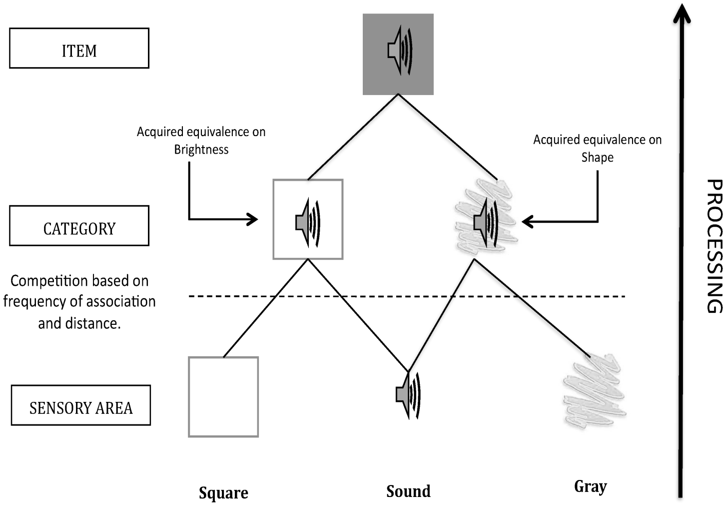

Figure 6: Illustration of multimodal hierarchical integration between features in long-term memory (adapted from Murray & Bussey, 2007).

nature. As a consequence, the distinction between memory and perception might be only at phenomenological level. In other words, it is the subjective attribution (wether to a component perceptually present or absent) to the cognitive activity that would determine the nature of this activity.

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