How Does Featural Salience Affect Semantic Control Processes? A Preliminary Study

Maria Montefinese*[1], Glyn, Hallam[2], Beth Jefferies[2]
[1] University of Chieti, Department of Neuroscience and Imaging, Chieti, Italy
[2] University of York, Department of Psychology, York, United Kingdom
*maria.montefinese@gmail.com

Abstract

Patients with multimodal semantic impairment following stroke (referred to here as 'semantic aphasia', SA) are highly sensitive to the cognitive control demands of the task being performed and poor at inhibiting strongly associated distracters and focusing on less dominant aspects of meaning. Here, using feature selection tasks, we tested the role played by a semantic measure of featural salience on the control processes in healthy participants (Experiment 1) and SA patients (Experiment 2). Healthy participants showed a worse performance when the distracter feature was highly salient and the target feature was less salient for the concept, i.e., when there was an interference with voluntary selection of the target feature (Experiment 1). Consistent with these results, the SA patients showed a poorer performance than older controls when the target feature was weakly related to the concept (Experiment 2). In line with the feature-based models of the semantic memory, we discuss these preliminary results in term of greater demands of controlled semantic retrieval when the features are weakly related to the concept in the semantic network.

Keywords: semantic impairment; semantic control; feature selection task

Introduction

In the course of our life, we acquire an enormous amount of knowledge about the world from experience, including general facts, concepts, and word meanings. Making productive use of this knowledge to understand stimuli and to guide behavior in a highly complex environment demands an ability to recover and select efficiently and reliably the stored knowledge. This capacity takes the name of semantic cognition and relies on at least two interacting components: 1) stored semantic knowledge -i.e., semantic memory; 2) executive processes which help to direct and control semantic activation in line with current goals and constraints -i.e., semantic control processes (Jefferies & Lambon Ralph, 2006).

This latter component can be impaired in brain-injured patient groups with lesions in a left prefrontal and temporoparietal distributed network, involving the left inferior frontal cortex, posterior middle temporal gyrus and intraparietal sulcus (Jefferies, 2013). The profile of this type of patients is termed 'semantic aphasia' (SA) and it is characterized mainly by verbal comprehension impairments accompanied by multimodal semantic ones. The peculiar qualitative trait of these patients is their high sensibility to the cognitive control demands of the task being performed. Indeed, SA patients show poor understanding of words with multiple meanings, since they are unable to select from competing semantic representations, due to their deregulated semantic control over semantic/linguistic activation (Noonan, Jefferies, Corbett, & Lambon Ralph, 2010).

Here, we investigated the role played by a featural salience measure -the semantic relevance (Sartori & Lombardi, 2004)- in the semantic control processes in two experiments, conducted in line with the feature-based models of the semantic memory (McRae, Cree, & Seidenberg, 2005; Montefinese, Ambrosini, Fairfield, & Mammarella, 2013a, b; Montefinese, Zannino, & Ambrosini, 2014; Vinson & Vigliocco, 2008). These models assume that concepts are described as distributed patterns of activity across sets of semantic features, which contribute, with different weights, to the meaning of a concept. Recently, Sartori and Lombardi (2004) proposed a new feature-based model of semantic memory, in which they proposed a novel index of feature importance, termed semantic relevance. According to the authors, semantic relevance captures the "core" meaning of a concept better than other featural measures, suggesting that the relevance of semantic features may be an organizing principle in semantic memory.

In Experiment 1 we tried to simulate the performance of SA patients in healthy individuals by compromising their executive control capacity by means of a concomitant n-back task during a semantic feature selection task. In Experiment 2, with a similar semantic task, we investigated the executive control deficits in the SA patients[1].

We expected a poorer performance for young participants under dual task condition, as well as for SA patients, when the target feature to be selected was weakly related to the concept (i.e., when it had a lower semantic relevance value), since this condition requires additional executive resources and a controlled semantic retrieval, compared to when the target feature was strongly related to the concept (i.e., when it had a higher semantic relevance value), since in this condition the retrieval of the target feature benefited from automatic spreading activation and semantic control demands were minimal.

[1] In Experiment 1, we chose to use a group of young participants since the most of semantic norms are derived from samples of similar age, thus allowing a better control over confounding variables of the studied process.

Experiment 1

Method

Participants: Twenty-six right-handed native English speakers (21 females; mean age: 20.58, *SD* = 2.21) from the University of York participated in this study. Their mean years of education were 14.73 (*SD* = 1.84).

Materials and Procedure: We selected the stimulus set and semantic measures from McRae and colleagues' (2005) database, which was collected with a feature-listing task. Stimuli consisted of 128 English words denoting exemplar-level concepts (cue concepts) and the same number of target, distracter, and false features. In each trial, a cue concept appeared above a row of three words denoting two features true of the cue concept (one target feature and one distracter) and one feature false of the concept. From this total set of stimuli, we created four blocks of 32 trials for each of the four possible semantic relations that the concept shared with the target feature. In particular, the target feature could indicate 1) the category to which the concept belonged; 2) a part of the concept; 3) an action that the concept could do; 4) the material that the concept was made from. For example, for this latter semantic relation, the cue concept could be FORK the true target feature could be STEEL (that shared the semantic relation required from the task with the concept), the true distractor feature could be PRONGS (that shared a semantic relation different from that required), and the false feature could be PHONE (that did not share a semantic relation with the concept).

To test our aim, we manipulated the semantic relevance indicating the strength of the semantic relation between cue concept and target or distracter feature. Within each block, in half of the items the target feature took a high relevance value and the distracter feature took a low relevance value, and vice versa in the other half. This allowed us to obtain two experimental conditions (High Relevance Target, HRT, and Low Relevance Target, LRT, respectively). Moreover, half of the trials were performed under the single task condition (i.e., participants performed the feature selection task alone), and the other half of the trials were performed under the dual task condition (i.e., participants concurrently performed the 1-back task).

For the 1-back task, a series of 10 random digits from 1 to 9 were presented and participants listened to the first number of the series without responding and, for each subsequent number, they attempted to say the digit that they heard on the previous trial. Next, participants performed the feature selection task (with and without the concurrent secondary 1-back task), in which they were asked to indicate which of the three features shared that particular semantic relation with the cue concept by pressing one of three buttons with their right hand, corresponding to the position of the response item (left, middle, and right). In the last block, participants performed the 1-back task under single task conditions again.

Results

We used repeated-measures ANOVA to examine the effects of Task (Single, Dual) and Condition (HRT, LRT) on log-transformed reaction times. We found the main effects of the Task ($F_{1,25} = 43.18$; $p < 0.0001$) and Condition ($F_{1,25} = 32.84$; $p < 0.0001$) factors, as well as the Task by Condition interaction ($F_{1,25} = 4.71$; $p < 0.0396$). The Bonferroni's post hoc analysis showed that participants were faster in the HRT than LRT condition, especially for the Dual task ($p < 0.0001$). Indeed, we also found a significant difference between the two HRT and LRT conditions for the Single task ($p < 0.0001$), albeit this effect was significantly smaller compared with that observed in the Dual task.

The ANOVA on response accuracy showed results that are in line with the reaction times analysis. Indeed, the main effect of Task was significant ($F_{1,25} = 9.59$; $p = 0.0048$), as well as the main effect of Condition ($F_{1,25} = 10$; $p < 0.0001$) and the interaction between Task and Condition ($F_{1,25} = 18.28$; $p = 0.0002$). As shown by the Bonferroni's post hoc analysis, participants showed a better accuracy for the HRT condition than the LRT one in the Dual task ($p < 0.0001$), supporting what observed for the reaction times. On the contrary, in the Single task, no difference emerged between the two conditions ($p = 1$).

Experiment 2

Method

Participants: Five SA patients (3 females; mean age: 62.4, *SD* = 7.6) and thirteen older controls (7 females; mean age: 68.38, *SD* = 7.29) participated to the study. Their mean years of education were 16.6 (*SD* = 1.34) and 19 (*SD* = 4.47) for the patients and controls, respectively. No significant difference was found for the age ($t_{(16)} = 1.54$; $p = .14$) and education level between the two groups ($t_{(16)} = 1.16$; $p = .26$).

Materials and Procedure: We selected the stimulus set and semantic measures from McRae and colleagues' (2005) database. Stimuli consisted of 72 English words denoting exemplar-level concepts (cue concepts) and the same number of target features. In each trial, a cue concept appeared above a row of three words denoting a feature true of the cue concept (the target feature) and two features false of the concept. To test our aim, we manipulated the semantic relevance of the target feature: in half of the items the target feature took a high relevance value and vice versa in the other half. This allowed us to obtain two experimental conditions (High Relevance Target, HRT, and Low Relevance Target, LRT, respectively).

Participants performed a feature selection task, in which they were asked to indicate which of the three features was reasonably true of the cue concept by pressing one of three buttons, corresponding to the position of the response item (left, middle, and right), with their right hand. In the present experiment, accuracy was stressed over speed (indeed, participants had 15000 ms to give their response) because of well-known variability of the patients' response times. For this reason, the response times were not analyzed.

Results

We analyzed the response accuracy by carrying out a mixed design ANOVA with Group (Patients, Controls) as between-subjects factor and Condition (HRT, LRT) as within-subjects factor. Table 1 shows descriptive statistics of the response accuracy of control participants, as well as the response accuracy of each patient. The main effect of Group was significant ($F_{1,16} = 6.46$; $p = 0.0218$), as well as the main effect of Condition ($F_{1,16} = 7.76$; $p = 0.0132$). Moreover, the interaction between Task and Condition was significant ($F_{1,16} = 5.28$; $p = 0.0345$). As shown by the Bonferroni's post-hoc test, the two groups differed significantly in the LRT condition ($p = 0.0383$), with lower accuracy for the patients, but not in the HRT condition ($p = 0.5122$). These between-differences were due to different patterns of performance in the patient and older participants. Indeed, older controls showed no significant difference between the HRT and LRT conditions ($p = 1$); on the contrary, compared to the HRT condition, patients' performance was worse in the LRT condition ($p = 0.05$).

	HRT	LRT
Control group		
Median	100%	100%
IQR	2.78%	2.78%
Patient group		
PP01	97.22%	94.44%
PP02	77.78%	63.89%
PP03	94.44%	91.67%
PP04	100%	97.22%
PP05	97.22%	97.22%

Table 1: Response accuracy for the control group and for each patient as a function of the experimental condition. IQR = interquantile range.

Discussion

We here examined the effect of a semantic featural dimension -the semantic relevance- on the semantic control processes across two feature selection experiments. To this aim, we created two experimental conditions, differing in the degree and form of semantic control required (i.e., low executive demands and automatic spreading of activation for HRT conditions and high executive demands and controlled semantic retrieval for LRT conditions) and asked participants to carry out a feature selection task.

First, our findings support feature-based models of the semantic memory (McRae et al., 2005; Montefinese et al., 2014a; Vinson & Vigliocco, 2008), showing that features with different degrees of importance in conceptual representation (i.e., low vs. high relevance features) contribute with different weights to the representation of its meaning (Montefinese, Ambrosini, Fairfield, & Mammarella, 2014; Sartori & Lombardi, 2004). Moreover, the findings from the Experiment 1 showed that the dual task condition produced a greater disruption -in terms of both reaction times and accuracy- for the condition with high relevance distracter, that is, when the need of semantic control was higher. In other words, under dual task condition, participants' performance was worse when controlled semantic retrieval was required (LRT condition), i.e., when they had to voluntarily focus their attention on the task-relevant target feature with low semantic relevance while inhibiting the selection of the task-irrelevant (but highly related to the cue concept) distracter feature; on the contrary, participants' performance was better when a strong automatic spread of activation occurred (HRT condition), i.e., when they could benefit of the stimulus-driven activation of the task-relevant target feature with high semantic relevance, without the need to inhibit the task-irrelevant distracter feature, which in this case was weakly related to the cue concept. This pattern of performance is similar to that seen in SA patients and confirms the view that distracter words strongly associated in the lexical/semantic network entail greater executive control demands to be inhibited and to concurrently focus on aspects of meaning that are relevant for a given task, in our case the specific semantic relation shared between the cue and the low relevance target (Noonan et al., 2010).

Next, we tested the prediction on the semantic control impairment following stroke on a sample of SA patients (Experiment 2). In line with the results obtained on the young participants, SA patients showed a worse performance when they made decisions about the meaning of LRT features than HRT features. In fact, the former did not benefit from the automatic spreading of the activation from cue concept to the target feature, because of their weak link. Thus, the greater control executive that was required in this condition (i.e., semantic controlled retrieval) determined a poorer performance in SA patients.

In sum, in the present study we provided the first evidence on the interplay between semantic control processes and feature-based distributed semantics, by showing how a measure of featural salience is able to modulate the semantic control processes. Indeed, the selection of the target features with low relevance value, which require greater semantic control compared to those with high relevance value, was impaired both in healthy participants during the execution of a secondary task tapping the executive control and in the SA patients. However, because of the relatively small sample size of the patients and the unequal number of patient and control samples, these results should be taken with caution and future research is needed to extend and confirm these preliminary results with a greater sample of SA patients.

Acknowledgments

We are indebted to the patients and their carers for their generous assistance with this study. The work was supported by a study visit grant from the Experimental Psychology Society to MM.

References

Jefferies, E. (2013). The neural basis of semantic cognition: converging evidence from neuropsychology, neuroimaging and TMS. *Cortex, 49*, 611-625.

Jefferies, E., & Ralph, M. A. L. (2006). Semantic impairment in stroke aphasia versus semantic dementia: a case-series comparison. *Brain*,*129*, 2132-2147.

McRae, K., Cree, G. S., Seidenberg, M. S., & McNorgan, C. (2005). Semantic feature production norms for a large set of living and nonliving things. *Behavior research methods*, *37*, 547-559.

Montefinese, M., Ambrosini, E., Fairfield, B., & Mammarella, N. (2013a). Semantic memory: A feature-based analysis and new norms for Italian. *Behavior research methods*, *45*, 440-461.

Montefinese, M., Ambrosini, E., Fairfield, B., & Mammarella, N. (2013b). The "subjective" pupil old/new effect: Is the truth plain to see?. *International Journal of Psychophysiology*, *89*, 48-56.

Montefinese, M., Ambrosini, E., Fairfield, B., & Mammarella, N. (2014). Semantic significance: a new measure of feature salience. *Memory & Cognition*,*42*, 355-369.

Montefinese, M., Zannino, G. D., & Ambrosini, E. (2014). Semantic similarity between old and new items produces false alarms in recognition memory. *Psychological research*, 1-10.

Noonan, K. A., Jefferies, E., Corbett, F., & Lambon Ralph, M. A. (2010). Elucidating the nature of deregulated semantic cognition in semantic aphasia: evidence for the roles of the prefrontal and temporoparietal cortices. *Journal of Cognitive Neuroscience, 22,* 1597–1613.

Sartori, G., & Lombardi, L. (2004). Semantic relevance and semantic disorders. *Journal of Cognitive Neuroscience*, *16*, 439-452.

Vinson, D. P., & Vigliocco, G. (2008). Semantic feature production norms for a large set of objects and events. *Behavior Research Methods, 40*, 183-190.