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Deficits of semantic control disproportionately affect low-relevance conceptual features: Evidence from semantic aphasia

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Abstract

Background: The ability to efficiently select specific aspects of our semantic representations that are relevant for current goals or the context is supported by semantic control processes (controlled semantic cognition framework). This semantic control component is impaired in patients with semantic aphasia, who have multimodal semantic impairment following left hemisphere stroke and are highly sensitive to the control demands of semantic tasks. However, relatively little is known about how this control deficit interacts with aspects of semantic representation.

Aims: Here we tested whether the relevance of semantic features can influence the demands of control resources in the selection of information within the semantic store in patients with semantic aphasia.

Methods & Procedure: Participants performed a feature selection task, where they were asked to indicate which of three features was semantically related to a given concept.

Outcomes & Results: We found that patients with semantic aphasia had a greater impairment on low relevance features, suggesting that the selection of target features with low relevance requires greater semantic control than target features with high relevance.

Conclusions: Our results confirm the necessity of control processes for the selection of aspects of conceptual knowledge that are only weakly activated within semantic storage when these are task-relevant. The study therefore highlights that semantic cognition emerges from the interaction of control and representational systems.

Keywords: semantic control; feature relevance; semantic selection; semantic aphasia

Introduction

Over the course of our life we acquire an enormous amount of knowledge about the world, including objects, word meanings, facts and people, without connection to any particular time or place – referred to as *semantic representation* (Tulving, 1972). According to distributed feature-based models of semantic representation (McRae, Cree, & Seidenberg, 2005; Montefinese, Zannino, & Ambrosini, 2015; Montefinese, Ciavarro & Ambrosini, 2015; Montefinese, Vinson, Ambrosini, 2018; Vinson & Vigliocco, 2008) concepts are described as distributed patterns of activity across sets of semantic features which contribute, with different weights, to the meaning of a concept (Montefinese, Ambrosini, Fairfield, Mammarella, 2013a, b, c; Montefinese, 2019).

Researchers have proposed an index of feature relevance for conceptual representation, termed *semantic relevance*, an emergent property of semantic representation (Sartori & Lombardi, 2004; Mechelli, Cappa, & Sartori, 2011; Sartori et al., 2007 for the details about the calculations). This measure indicates the importance of a semantic feature in concept identification and it is a nonlinear combination of dominance (e.g., the proportion of participants who list the feature as connected to the concept) and distinctiveness (the salience of the feature for the concept given its neighbours, e.g., TRUNK is more distinctive than LEG at identifying the concept ELEPHANT). Thus, a feature which captures the core meaning of a concept will have both high dominance and high distinctiveness. *Semantic relevance* has been found to predict performance better than other measures of feature salience, such as distinctiveness and dominance alone (Montefinese, Ambrosini, Fairfield & Mammarella, 2014; Montefinese & Vinson, 2015). Additionally it also accounts for many of the observed phenomena in semantic representation disorders, such as, the category-specific deficits for living things in patients with Alzheimer's disease (Sartori & Lombardi, 2004; Sartori, Lombardi & Mattiuzzi, 2005) and herpes simplex virus encephalitis (Sartori & Lombardi, 2004). In particular, the authors found that when the relevance level of the conceptual features between living and non-living categories was equated, patients' category-specific impairment in naming-to-description tasks for living things disappeared.

This suggests that the relevance of semantic features predicts the storage deficit in patients with semantic disorders and may be an important organizing principle of conceptual semantic representation.

Conceptual and featural semantic information can be activated automatically or in a controlled way within semantic representation. Specifically, automatic and stimulus-driven (bottom-up) activation of semantic information benefits from automatic spreading activation (Masson, 1991; Neely, 1990; Collins & Loftus, 1975) and occurs with minimal control demands. By contrast, when the task at hand requires different information to be selected, or when automatically selected information is not relevant or useful, control processes play a role. These latter processes are separable from the long-term store of semantic knowledge (Jefferies, 2013; Jefferies & Lambon Ralph, 2006; Noonan, Jefferies, Visser & Lambon Ralph, 2013) and support the ability to efficiently and reliably retrieve and select specific aspects of our semantic representations that are relevant for current goals or the context (*controlled semantic cognition* framework, Lambon Ralph, Jefferies, Patterson, Rogers, 2017).

Following the seminal work of Warrington and Shallice (1979), a long tradition of studies on semantic patients investigated the deficit in accessing semantic information (Warrington & Cipolotti, 1996; Warrington and McCarthy, 1983; Campanella, Mondani, Skrap & Shallice, 2008). In particular, it has been shown that this semantic control component is impaired in semantic aphasia (SA) patients with infarcts affecting inferior frontal and temporoparietal brain regions (Jefferies, 2013). This results in difficulties in manipulating the information within semantic representation in the context of an intact semantic store (Corbett, Jefferies, Ehsan, & Lambon Ralph, 2009; Corbett, Jefferies, & Lambon Ralph, 2009; Jefferies, Baker, Doran & Lambon Ralph, 2007; Jefferies & Lambon Ralph, 2006; Rogers, Patterson, Jefferies & Lambon Ralph, 2015), and cannot be explained by a storage deficit, as in patients with semantic dementia (SD). Following bilateral anterior temporal atrophy, SD patients show a degradation of core amodal semantic knowledge (Jefferies, 2013).

While SD patients are consistent across different semantic tasks that tapped the same concepts, SA patients show inconsistent performance (Jefferies & Lambon Ralph, 2006; Warrington & Cipollotti, 1996; Campanella, Mondani, Skrap & Shallice, 2008) and difficulties in inhibiting dominant distractors or retrieving distant relationships between concepts and less relevant meaning dimensions (e.g., linking SHOWER with OVEN as household items, compared to SHOWER with BATH; Noonan, Jefferies, Corbett & Lambon Ralph, 2010). SA patients also show an improvement following cues that provide external constraints on retrieval (Corbett, Jefferies, & Ralph, 2011; Jefferies, Patterson, & Ralph, 2008) and an equivalent impairment across modalities when control demands are held constant (Corbett et al., 2009a; Corbett et al., 2009b; Gardner et al., 2012), indicating that their problem does not stem from a loss of knowledge as in SD, but it rather depends on the control demands. In SA patients, non-semantic executive control deficits parallel problems in the semantic domain (Jefferies & Ralph, 2006), while they are largely spared in SD. However, although SD patients show somewhat larger effects of word imageability than SA patients, both are better at retrieving the meaning of highly imageable items, such as APPLE, compared with abstract words such as TRUTH (Jefferies, Hoffman, Jones & Lambon Ralph, 2008). Similarly, less frequent concepts are more vulnerable to damage in SD (given their weaker links within semantic representation because they are encountered less often during the life course). In contrast, SA patients show no benefit of frequency: linking SUN and MOON is no easier than CHESTNUT and CONKER, despite the former being more frequent than the latter (Jefferies, Patterson, Jones, & Lambon Ralph, 2009). Rather, SA patients often show absent or reverse frequency effects: high frequency words exert greater demands on cognitive control because they tend to appear in a broader range of linguistic contexts and have more variable meanings (Almaghyuli, Thompson, Lambon Ralph, & Jefferies, 2012). For example, the high frequency word FIRE refers to flames, but also losing a job, shooting a gun or filling someone with enthusiasm, and this diversity of meanings is thought to increase the control demands for these items (Almaghyuli et al., 2012; Hoffman, Rogers & Lambon Ralph, 2011). Collectively, the findings above suggest that the control demands of semantic tasks are influenced by properties of concepts and how they are organized within semantic representation (i.e., from the type and strength of relations among them). Task performance alone cannot establish if differences across conditions reflect the structure of knowledge directly or the role of semantic control processes; however, comparisons between groups of participants with different control capacities allow behavioural effects to be linked to control. The capacity of participants to control semantic retrieval and selection is disrupted in two circumstances: a) through the use of dual task methodology in healthy individuals or b) as a consequence of left hemisphere stroke in semantic aphasia (Almaghyuli et al., 2012; Jefferies & Lambon Ralph, 2006). In the current study, we compared patients with semantic aphasia to healthy controls in order to characterise the interaction of semantic relevance with control processes. Given that semantic relevance is a core property of the semantic store predicting deficits of semantic storage and, in particular, a measure of the relevance of a feature for conceptual representation (Sartori & Lombardi, 2004), we ask whether it can influence the demands of control resources in the selection of information within the semantic store in SA patients. Consistent with SA patients' impairment for weaker and less relevant aspects of meaning, less relevant features should require higher control demands compared with high relevance features because the latter should be activated more quickly and efficiently via automatic spreading of activation within the semantic network.

In a recent study, we tested this hypothesis in healthy individuals using dual task methodology during a semantic feature selection task (Montefinese, Hallam, Thompson & Jefferies, 2019). There was greater dual-task disruption as the relevance value of the distracter feature linearly increased, supporting the hypothesis that semantic relevance interacts with this aspect of semantic representation. In the current study we provide converging evidence for this pattern in SA patients, testing the contribution of featural relevance to semantic performance in individuals with deficits affecting the appropriate use of concepts when control demands are high. We predicted that the selection of features with lower semantic relevance would require greater control, while those with higher semantic relevance benefit more from automatic spreading activation within the semantic system (i.e., they are activated more quickly and efficiently). Consequently, SA patients should show greater deficits (relative to age-matched controls), when the target feature to be selected has a lower relevance value compared to higher relevance features.

Method

Participants

Seven stroke aphasia patients (five females; mean age: 60.43, *SD* = 7.97; mean years of education: 16.43, *SD* = 1.13) were included in the study. Patients were all native English speakers, and recruited through stroke and aphasia groups across Yorkshire, UK. The patients were compared with thirteen control participants (seven females; mean age: 67.38, *SD* = 7.04; mean education: 18.07, *SD* = 3.04). They were similar to the patients in terms of age ($t_{(18)}$= 1.939, p = .0684) and education ($t_{(18)}$= 1.736, p = .0997). None of the controls had a history of neurological illness or mental decline, and they were all native English speakers.

In this study a sensitivity power analysis revealed that, even assuming 7 patients and 7 control participants, our sample is large enough to detect a significant interaction with a medium effect size of d = .57 (assuming power .80 and a correlation between repeated measures of .75). This effect size is conservatively in line with the results of the (multiple-experiment) study more similar to ours from the same researchers' group (Noonan et al., 2010), that used smaller samples of participants showing extreme effect sizes (average d = 1.86), even supposing an important overestimate of the effect sizes because to the small sample.

The study was approved by the local ethics committee and was performed in accordance with the ethical standards of the 2013 Declaration of Helsinki for human studies (World Medical Association).

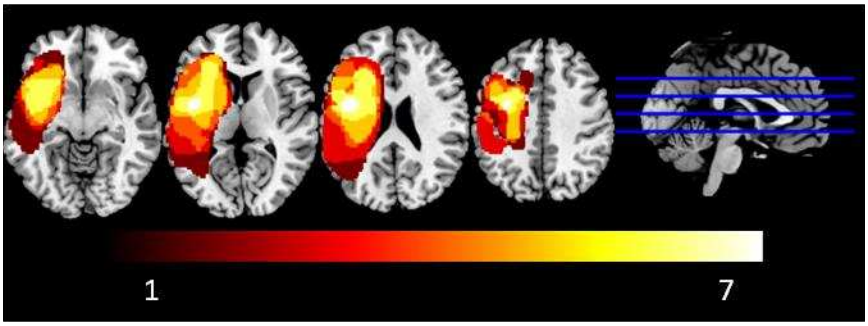

Figure 1. Lesion overlay map of semantic aphasia cases.

Inclusion criteria

All the patients had left frontoparietal infarcts (see Figure 1). Patients had chronic impairment resulting from a cerebrovascular accident at least a year previously. Patients often displayed more executive and general language impairments (see Table 1). Semantic aphasia transcends classical 'Boston' aphasia classifications, and patients can present different aphasia profiles as their spoken language skills are variable. In line with the original use of the term "semantic aphasia" by Henry Head (1926) and the inclusion criteria proposed by Jefferies and Lambon Ralph (2006), the patients in this study showed deficits affecting the appropriate use of concepts presented as words and objects when control demands were high. In addition to verbal semantic problems, they were impaired on at least one non-verbal task: Ambiguity task (Noonan et al., 2010) and Camel and Cactus Test (CCT)-words (Bozeat et al., 2000) were used to assess the verbal modality, whereas CCT-pictures (Bozeat et al., 2000) and/or Object use task (Corbett et al., 2010) were used as non-verbal tasks (details below and in Table 1). There were no other inclusion/exclusion criteria.

Background neuropsychological assessment

Semantic memory assessment: Cambridge Semantic Battery

This assesses semantic retrieval for a set of 64 items across tasks (Bozeat et al., 2000), including picture naming, word-picture matching, verbal and pictorial semantic associations (CCT). Patients showed large variability during picture naming reflecting additional phonological deficits in some cases [proportion correct *M* (*SD*) = .37 (.38)]. In contrast, performance was uniformly at ceiling in word-picture matching [*M* (*SD*) = .95 (.06)], indicating intact comprehension in tasks with minimal control demands. When secondary associations between concepts were to be retrieved on the CCT with higher control demands, patient performance was lower [words *M* (*SD*) = .79 (.17); pictures *M* (*SD*) = .76 (.18)] with no differences across modalities (two-tailed paired sample *t*-test, $t_{(6)} = .671$; $p = .527$; Cohen's $d = .253$).

Table 1. Background neuropsychological performance

Test[a]	*Max*	*Normal Cutoff*	*Patients*						
			SSR	*LHN*	*NNF*	*RTJ*	*EKD*	*HNA*	*ETW*
Picture CCT	64	52.7	57	43*	29*	56	63	39*	50*
Word CCT	64	56.6	54*	44*	45*	61	58	31*	59
Word-Picture Matching	64	62.7	52*	62*	60*	63	64	63	61*
Picture Naming	64	59.1	3*	61	19*	46*	36*	1*	0*
Word Repetition	16	16	2*	14*	12*	6*	2*	0*	0*
Cookie Theft	-	-	0	18	9	38	NT	0	0
Ambiguity task									
(a) Dominant	30	28.4[d]	27*	18*	24*	27*	NT	22*	27*
(b) Subordinate	30	27.6[d]	19*	9*	14*	21*	NT	11*	17*
Object use task									
(a) Canonical	37	NA	33	31	29	37	37	32	33
(b) Non-canonical	37	33.9[d]	22*	13*	14*	32*	32*	14*	24*
Category Fluency[b]	-	9.2[d]	0*	7*	5*	15	0*	0*	0*
Letter Fluency[c]	-	8.6[d]	0*	3*	0*	7*	0*	0*	0*
Digit Span Forward	9	5.5[d]	0*	4*	2*	6	4*	0*	0*
Digit Span Backward	8	3.67[d]	NT	2*	0*	4	NT	0*	0*
Trail Making Test (A)	24	24 [d]	24	22*	23*	24	NT	19*	14*
Trail Making Test (B)	23	17.4 [d]	23	23	16*	21	NT	2*	NT
Brixton	54	28	31	7*	18*	40	39	21*	6*
RCPM	36	28	34	29	31	33	32	31	32

NA = not available for the canonical condition given near-ceiling performance (Corbett et al., 2011). NT = not tested. *below normal cut off. [a] Table shows raw scores. [b] category fluency = animals, fruit, birds, breeds of dog, household objects, tools, vehicles, types of boat; [c] letter fluency = 'F, A, S'. [d] = Cut-off scores are from healthy controls tested at the University of York (mean minus two standard deviations). CCT = Camel and cactus test (CCT; Bozeat et al., 2000). CCT picture/word, picture naming and Spoken Word-Picture Matching from the Cambridge Semantic Battery (Bozeat et al., 2000). Word repetition is a subset of 16 items from PALPA (Psycholinguistic Assessments of Language Processing in Aphasia, Kay, Coltheart & Lesser, 1992). Cookie Theft = picture description by Goodglass and Kaplan (1983) (words/minute). Ambiguity task = homonym association matching task (Noonan et al., 2010), and the object use task is from Corbett et al. (2011). RCPM = Raven's Coloured Progressive Matrices (Raven, 1962); Brixton = Brixton Spatial Rule Attainment Task (Burgess and Shallice, 1997).

Tests of semantic control

Ambiguity task. Semantic judgements (60 items) on polysemous words to test comprehension of dominant and subordinate meanings of words (Noonan et al., 2010). All patients, with the exception of EKD who did not complete the test, were below the normal cut-off in both the conditions. Patients showed better comprehension for dominant than for subordinate interpretations [proportion correct: dominant *M* (*SD*): .81 (.12); subordinate *M* (*SD*) = .51 (.16), $t_{(5)} = 12.324$, $p < .001$, $d = 5.031$].

Object use task. This task (74 items) involved selecting (among five distractors) either the canonical or the alternative object to accomplish a task, with all items represented as photographs (Corbett et al., 2010). Five patients out of seven were poor at selecting non-canonical targets [proportion correct: canonical *M* (*SD*) = .75 (.34); non-canonical *M* (*SD*) = .46 (.28); $t_{(5)} = 5.920$, $p = .002$; $d = 2.417$]. One single patient (RTJ) was not below the normal cut-off in the non-canonical condition, however this patient was impaired in the subordinate condition of the ambiguity task. EKD performance has not been tested in this task.

Apparatus and stimuli

The task was a feature selection task, where participants were asked to indicate which of three features was semantically related to a given concept. We selected the stimuli from McRae and colleagues' (2005) feature-listing database. There were 72 English words denoting exemplar-level concepts (used as cues) and the same number of features related to the concepts (used as targets), which were chosen on the basis of their relevance value (see below) and 144 unrelated features (used as distractors). In each trial, a word denoting a cue concept was presented at the top of the computer screen above a row of three words denoting one feature related to the cue concept (the target feature) and two unrelated features (the distractors) to the cue concept (see Figure 2 for an example). All the words were presented in black 24-point Verdana font against a white background.

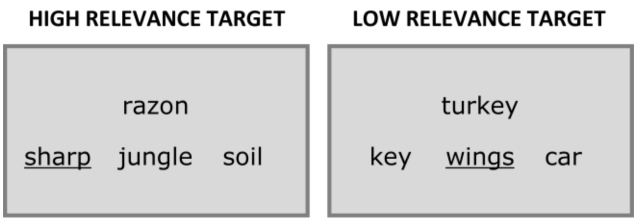

Figure 2. Example trials. Participants had to select the target feature (underlined) may take different degrees of relevance for the probe concept above, in one of the following semantic conditions: high relevance target (HRT), and low relevance target (LRT). The two distracters (in regular font) were unrelated to the probe concept.

To test our hypothesis, we manipulated the semantic relevance between the cue concept and target feature. The semantic relevance value for each true feature-concept pair was calculated as $k_{ij} = 10x_{ij} \times \ln(I/I_j)$ (see Sartori et al., 2007), where x_{ij} indicates the dominance of a feature *j* in a concept *i* and represents the local component of k_{ij}, *I* indicates the total number of concepts in McRae et al.'s norms (i.e., 541), I_j indicates the number of concepts in which the feature *j* appears, and $\ln(I/I_j)$ represents the global component of k_{ij}. We then dichotomised the items, so that half were 'strongly related' and half were 'weakly related' (see Figure 2 for an example). This allowed us to obtain two experimental conditions: High Relevance Target (HRT) with a mean semantic relevance of 28.06 (*SD* = 6.22), and Low Relevance Target (LRT) with a mean semantic relevance of 11.69 (*SD* = 4.84). As expected, these conditions had significantly different relevance scores: $t_{(70)} = -13.140$; $p < .001$; Cohen's $d = 3.097$. The words denoting concepts and features were only presented once. We matched five semantic/lexical variables (see Table 2 for a description) between the two relevance conditions ($ts_{(70)} < -1.886$, *p*s >.064; $d < .444$). We also performed a repeated measure analysis of variance (ANOVA) on the continuous relevance measure with condition (HRT, LRT) and word class (adjective, noun, and verb) factors. We observed a non-significant two-way interaction ($F_{(2,66)} = 1.457$, $p = .240$, $\eta^2_p = .042$) showing that mean relevance values was balanced across word classes (i.e., adjective, noun and verb). Because the distractor features did not share a true relation with the cue concept (and therefore no calculation of semantic dimensions was possible for them), they were balanced for the word length between HRT and LRT conditions only ($t_{(70)} = 1.676$; $p = .098$; Cohen's $d = .395$). There were six practice trials, half in each condition.

Table 2. Semantic/lexical variables matched between HRT and LRT conditions.

Variable	Explanation	HRT	LRT
Stimulus length	Number of letters in concept and feature	18.3(5.6)	17.2(4.2)
Concreteness[a]	Mean concreteness rating (1–5 scale, 5 = *concrete*)	4.9(.13)	4.9(.14)
Word frequency[b]	Natural logarithm of word frequency	6.4(1.3)	6.4(1.5)
Familiarity[b]	Mean familiarity rating (1–9 scale, 9 = *extremely familiar*)	6.2(1.6)	5.4(2.0)
Number of features[b]	Total number of features, listed for a given concept	13.7(3.4)	14.6(3.8)
Inter-correlational Strength[b]	Strength with which a feature is correlated with the other features of a concept	49.6(65.9)	25.1(41.7)

[a] Derived from Brysbaert, Warriner and Kuperman (2014); [b] derived from McRae and others (2005); HRT, High Relevance Target; LRT, Low Relevance Target.

Procedure

Instructions were delivered via the computer with an example at the beginning of the experiment. In each trial a fixation cross (2500 ms) was presented at the centre of the screen, followed by a slide showing the experimental stimulus.

Participants were asked to indicate which of the three words denoting features (the true target and two unrelated and false distractors of the cue concept) shared a true semantic relation with a cue word denoting a concept. Participants manually responded with their right hand via keyboard's numeric keypad by pressing buttons 1, 2, 3 corresponding to the position on the screen of the feature chosen. The stimulus disappeared at the onset of participants' response. Stimulus presentation lasted up to a maximum of 15000 msec. For example, the cue word (concept GLOVES) appeared above a row of three words, one target feature (low or high relevant for the concept, e.g., LEATHER) to be selected and two distracter features unrelated to the concept (e.g., JUNGLE and SOIL) and irrelevant for the task (see McRae, de Sa, & Seidenberg, 1997; Montefinese, Ambrosini, Fairfield, & Mammarella, 2014). Participants completed 72 experimental trials: 36 of the trials belonged to the LRT condition, and the other 36 to the HRT condition. The order of presentation of the trials was randomized across participants.

Data analysis

Reaction time (RT) and accuracy data are displayed in Table 3. We used a mixed design ANOVA with group (patients, controls) as between-subjects factor and condition (HRT, LRT) as within-subjects factor. Incorrect responses were excluded from the RT analysis (4%). We logarithmically transformed the remaining RT data to satisfy assumptions of normality. Bonferroni post-hoc tests were used. The alpha level was set to .05 and the effect sizes are reported as partial eta-squared (η^2_p).

Table 3. Descriptive statistics for reaction times and accuracy.

	RTs [ln(ms)]		Accuracy (%)	
	M	*SD*	*M*	*SD*
Condition				
HRT	8.11	0.58	96.67	5.88
LRT	8.22	0.58	94.58	9.56
Group				
Controls	7.85	0.34	98.93	1.59
Patients	8.73	0.74	89.48	0.96
Interaction				
Controls-HRT	7.79	0.34	99.15	1.33
Controls-LRT	7.91	0.33	98.72	1.83
Patients-HRT	8.68	0.47	92.06	8.24
Patients-LRT	8.79	0.51	86.90	13.29

HRT = High Relevance Target; LRT = Low Relevance Target; ln = natural logarithm

Results

Accuracy

There were main effects of group ($F_{(1,18)}$ = 10.297; p = .005, η^2_p = .364), and condition ($F_{(1,18)}$ = 11.601; p = .003, η^2_p = .392), plus an interaction between group and condition ($F_{(1,18)}$ = 8.323; p = .010, η^2_p = .316; see Figure 3). Post-hoc tests showed that the two groups differed significantly in the LRT condition ($t_{(20.776)}$ = 3.153, p = .005, d = .661), with lower accuracy for the patients. There was no group difference for the HRT condition ($t_{(20.776)}$ = 1.360, p = .189, d = .285). These between-group differences reflected worse performance on LRT than HRT trials in patients ($t_{(20.776)}$ = 3.073, p = .006, d = .644), with no difference between conditions in controls ($t_{(20.776)} < 1$, $p > .999$, d = .105). The interaction effect was confirmed by non-parametric Kruskal-Wallis ANOVA performed on the difference between LRT and HRT performance ($H_{(1)}$ = 5.592, p = .018, r = .529).

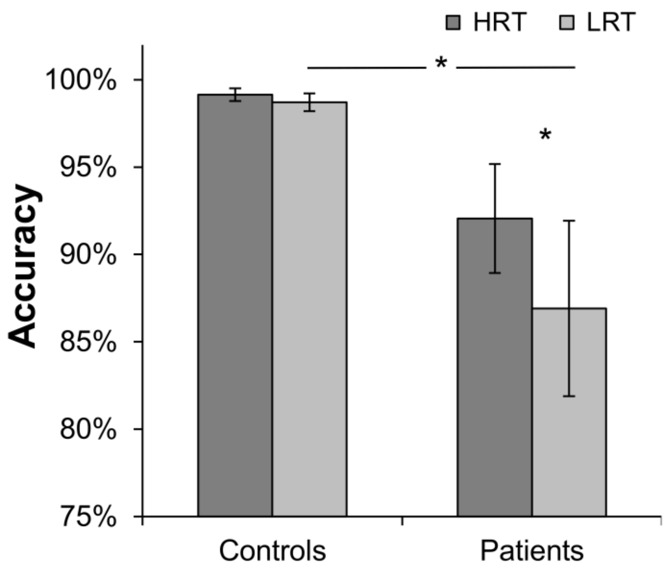

Figure 3. Mean accuracy is shown as a function of group (controls, patients) and condition (HRT, LRT) factors. Error bars indicate standard error of the mean. * = p < .01.

Reaction times

There were main effects of group ($F_{(1,18)}$ = 23.060; p < .001, η^2_p = .562) and condition ($F_{(1,18)}$ = 61.920; p < .001, η^2_p = .775), with slower RTs for patients than controls, and for LRT compared to HRT trials. The interaction between group and condition was not significant ($F_{(1,18)}$ = .256; p = .619, η^2_p = .014). Non-parametric Kruskal-Wallis ANOVA performed on the difference between LRT and HRT performance confirmed this result ($H_{(1)}$ = .567, p = .452, r = .168).

Discussion

In this study we tested, for the first time, the relationship between semantic control and featural relevance in a sample of patients with semantic aphasia, who showed deficits of semantic control following left fronto-parietal hemisphere stroke. We manipulated the relevance of target features to the probe concept, allowing us to contrast trials in which the relevant information would be activated more quickly and efficiently via automatic spreading of activation within the semantic network (i.e., high relevance features), therefore not requiring semantic control, with situations in which it was more difficult to select the relevant information (i.e., low relevance features), therefore requiring semantic control. This is the first time that feature relevance has been manipulated in people with a semantic control impairment.

SA patients showed poorer accuracy when they selected low relevance target features compared to high relevance target features, relative to healthy aged-matched controls who did not demonstrate this difference.

Thus, patients with deficient semantic control (Almaghyuli et al., 2012; Noonan et al., 2010) had reduced ability to efficiently select features of concepts that were less relevant to conceptual identity. These findings show for the first time how the difference in feature relevance within conceptual representation modulates the control demands of semantic tasks. These results confirm the necessity of control processes for the selection of aspects of conceptual knowledge that are only weakly activated within the semantic storage, supporting the view that semantic cognition emerges from the interaction of control and representational systems (Jefferies, 2013; Lambon Ralph & Jefferies 2006; Lambon Ralph et al., 2017). Although patients with SA fail the same range of verbal and nonverbal semantic tasks as patients with semantic storage deficit (e.g., with semantic dementia), their ability to select semantic information clearly varies with the semantic control demands of the task and item stimuli, indicating that the semantic store is relatively intact in the patients with SA. Rather, SA patients have difficulty in regulating the activation on-line within the semantic representation such that they fail to promote relevant aspects of knowledge, especially when it reflects non-dominant aspects of knowledge or weak links between concepts and features within semantic representation. This explains why SA patients struggle in selecting low relevant information in our feature selection task. In particular, in our current and previous (Montefinese et al., 2020) studies we showed that the semantic relevance of concept features constitutes another efficient way of manipulating semantic control demands in healthy individuals and SA patients. Past neuropsychological research showed that semantic relevance significantly predicted the deficit of semantic storage in patients with Alzheimer's disease and herpes simplex virus encephalitis (Sartori & Lombardi, 2004; Sartori et al., 2005). We corroborate these results with further neuropsychological evidence suggesting that semantic relevance is an organizing principle of semantic representation, and we extend them by showing that it can be used to modulate control demands in semantic tasks. Therefore, future studies should take into account the role of this measure and other variables of featural salience in modulating the task control demands.

We did not observe a significant interaction between group and relevance condition on participants' reaction time data. These results should be taken with caution given the small sample size and the larger standard deviation of reaction times in the patient group. However, we found a group difference, with longer reaction times for the patients compared to the control participants. It should be noted that because participants responded with their right hand (and given the location of patients' lesion in the left hemisphere) this significant effect could be due to right arm and hand weakness possibly present in a proportion of patients.

Importantly, in this study we used a set of stimuli controlled for a number of lexical-semantic variables that could affect patients' semantic performance. However, we could not control for imageability, a variable shown to affect performance of patients with semantic control and storage deficits), as imageability values were not available for our stimulus set. Therefore, we cannot exclude that the imageability did not differ across relevance conditions. Nonetheless, we controlled our stimuli for concreteness, a measure that in the past literature has been used interchangeably with the imageability (Binder et al., 2005; Fliessbach et al., 2006; Giesbrecht et al., 2004; Richardson, 2003).

Conclusion

The present study helps to characterise the interplay between semantic control and feature-based semantic representations. For the first time we tested the relationship between semantic control and featural relevance in a sample of patients with semantic aphasia, who showed deficits of semantic control following left fronto-parietal hemisphere stroke. We observed that patients with semantic aphasia showed poorer accuracy when they selected low relevance target features compared to high relevance target features, relative to healthy aged-matched controls who did not demonstrate this difference. These findings corroborate neuropsychological studies on patients with semantic storage impairment, suggesting that semantic relevance is an organizing principle of semantic representation. Moreover, they show that semantic relevance can be used to efficiently modulate control demands in semantic tasks. However, future research should investigate the role of this and other variables of featural salience in further semantic tasks that modulate control demands.

Disclosure statement

The authors report no conflict of interest.

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Data availability statement

Data available on request from the authors.

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