Named object drawing in semantic dementia reveals the graded, transmodal knowledge in the temporal lobe

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Introduction

How and where are semantics represented? A 'distributed' system of semantic memory has been proposed in which modality-associated cortices are interconnected to recall a complete memory (Huth et al., 2016). However, others have proposed a 'distributed plus hub' system in which a central transmodal semantic 'hub' links association cortices (Patterson et al., 2007; Lambon Ralph et al., 2017).

If such a 'hub' does exist, does it operate using a sparse, population-based neural code or with single neurons representing single concepts (Quian, 2005)?

Semantic dementia (SD) is a neurodegenerative disorder with selective impairment of semantic memory, in association with anterior temporal lobe neurodegeneration due to TDP-43 pathology. Here we use SD to investigate the "hub" for semantic knowledge and its coding system. We use the line drawings made by patients with SD as the principal data source, linked to structural brain imaging. Semantic dementia encompasses the semantic variant of primary progressive aphasia (cf. Gorno-Tempini et al 2011) and the right temporal homologue.

Aim

We investigate the loss of conceptual knowledge in patients with semantic dementia.

Many prior studies have used binary, recognition-based semantic assessments, which limits their ability to detect subtler variations in progressive memory decline. In contrast, we have previously used drawings to reveal and quantify the gradations in semantic deficits in people with semantic dementia.

Here, we examine line-drawings of objects and animals (such as 'cat' or 'airplane'), produced in response to their names, from semantic dementia patients, in conjunction with structural brain MRI data, to understand the organisation of semantic memory.

Method

- Line drawings from 19 patients diagnosed with semantic dementia at Addenbrooke's hospital were collated, and compared with drawings from 3 age-matched healthy controls.
- A composite score of semantic memory was calculated for drawings, with points for the presence of 'core' features identified by the authors; core features are those without which a drawing would not be an accurate representation of the object it depicts (e.g. the trunk of an elephant, the beak and wings of a duck).
- For a subset of 10 patients, grey-matter volumes in ventral stream regions of interest were extracted using voxel-based morphometry from brain MRI data and correlated against the semantic composite score in an exploratory analysis.
- Longitudinal drawings provide further insight into the gradual dissolution of conceptual knowledge in SD

Results

SD is associated with left-lateralised, bitemporal atrophy starting from the poles, but progressive semantic loss reflects grey matter loss from left inferior temporal gyrus

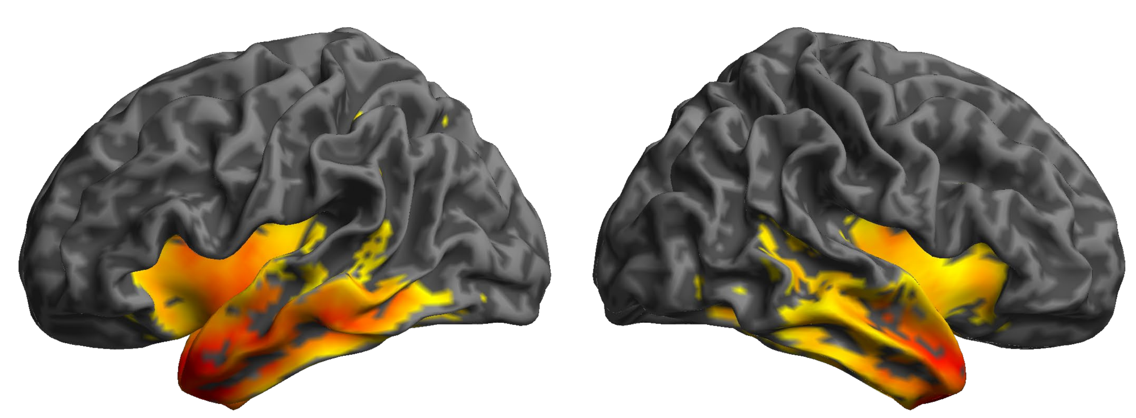

Figure 1. Voxel-based morphometry showing bilateral temporal lobe and insular grey-matter atrophy, averaged across 10 patients. Across three scoring normalisation methods, grey matter volume in left inferior temporal gyrus correlated with drawing performance (p=0.03-0.04). Right inferior temporal gyrus trend correlated with drawing performance using two methods (p=0.05-0.06) but not a third (0.21). There was no correlation between drawing performance and anterior temporal pole or fusiform gyrus in either hemisphere,

Semantic impairment is pan-category and independent of the stimulus modality of testing

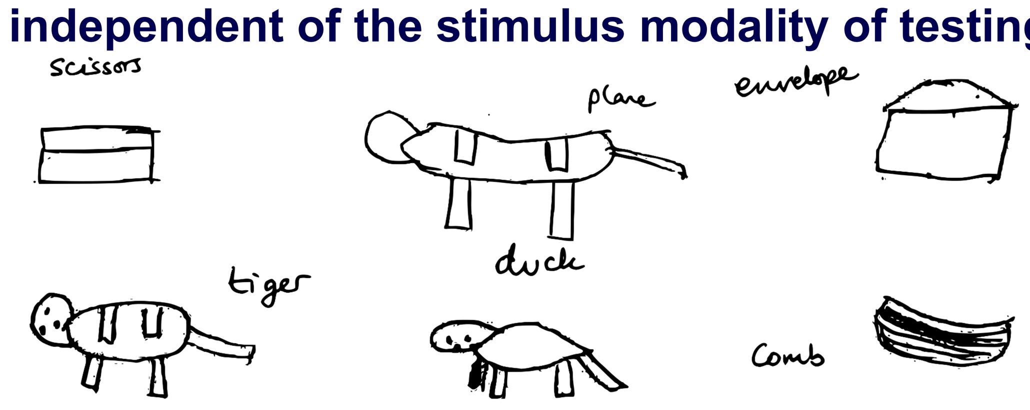

Figure 2. A single patient's drawings of objects from animate and inanimate categories, showing severe transmodal semantic impairment in the form of erroneous cross-category generalisations. Inanimate objects may become box-like (scissors) and gain animal-like features (plane with legs and tail).

Semantic memory is lost in a graded fashion

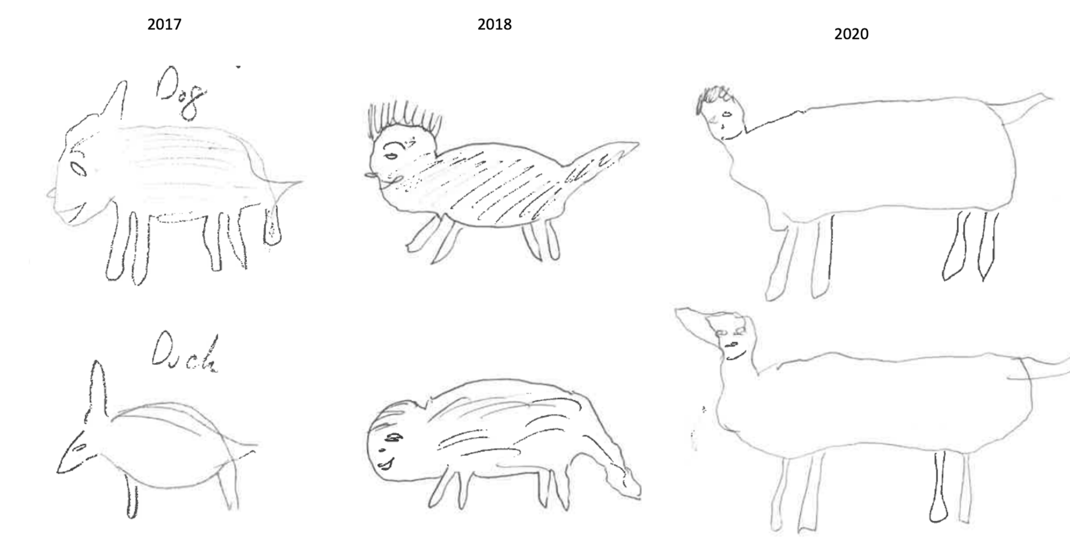

Figure 3. A single patient's drawings of a dog (top row) and duck (bottom row) over a 3 year time-span. Both animals are poor representations from the start, but become progressively less recognisable. The dog loses its snout and ears, while the duck loses its beak (2018) and is drawn without wings. Both animals gain human facial expressions (2020), and the duck becomes four-legged. The addition of these non-native features, and loss of expected features, is consistent with a progressive inability to resolve individual members of a semantically related category, with cross-category semantic generalisation errors.

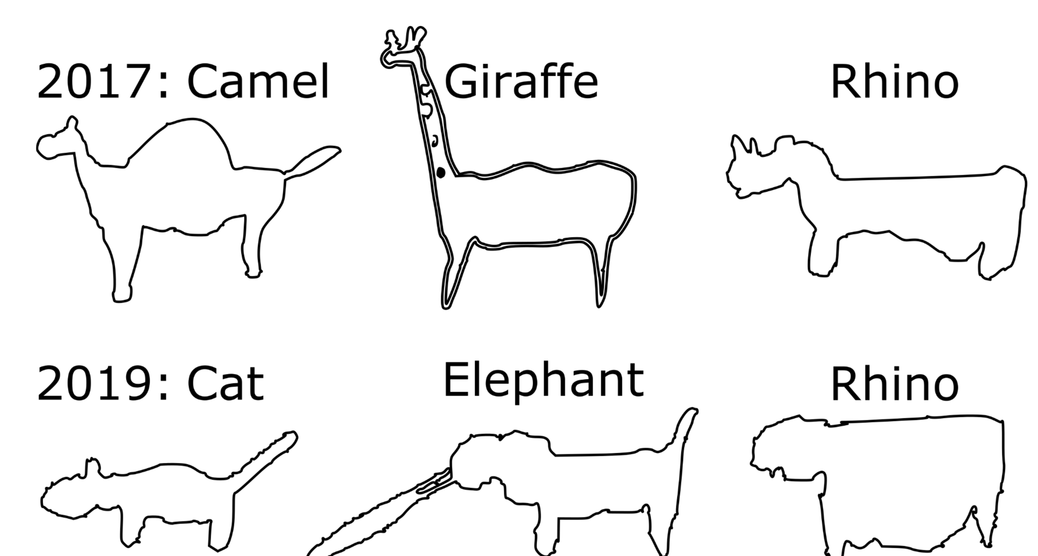

Figure 4. A single patient's drawings of a camel, giraffe and rhino in 2017. At this time, all three animals are distinct and resemble their living counterparts; the camel has a hump, the giraffe has a tall neck, spots, and misplaced but present horns, and the rhino has a stocky body compared with its head, with two horns. In 2019, the same patient draws a cat, elephant and duck, which at this stage no longer obviously resemble their living counterparts and are much less distinct from one another, with the duck resembling a land animal / mammal, exemplifying the 'prototypicality effect' that accompanies late-stage semantic dementia. The elephant retains its trunk, reflecting graded knowledge loss.

Discussion

Semi-quantitative line drawing assessments show a pattern of omissions and intrusions that indicate cross-category semantic generalization errors. Less frequently encountered concepts are lost early, and more frequently encountered concepts are liable to inappropriately intrude into other semantic concepts.

This cross-category, graded semantic deficit is associated with the progressive temporal lobe atrophy in SD, suggesting a role for the ATL as a central convergence zone.

The left ITG volume, but not the ATL volume, correlated statistically with semantic performance. The lack of correlation in ATL may be due to floor-effects, in that by the time of diagnosis the ATL was already severely atrophic while the adjacent ITG was still within a dynamic range of atrophy. Type II error is also possible for ATL correlations.

The graded nature of semantic deficits in SD suggest that the temporal lobe utilises a population-based code for storing semantic knowledge in a "distributed-plus-hub" model.

Conclusion

Line drawings are not only a simple clinical test in support of a diagnosis of SD. They also provide insights into the transmodal semantic deficit in SD. The results are consistent with a distributed-plus-hub model of semantic memory. The graded nature of deficit in semantic performance observed in our subset of longitudinally observed patients suggests the temporal lobe uses a population-code in its central convergence zone.

References

Huth et al, Nature, 2016

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Quian et al., Nature, 2005