Under-resourced or overloaded? Rethinking working memory deficits in developmental language disorder

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Developmental language disorder (DLD) involves deficits in language acquisition and use in the absence of any biomedical cause (e.g., Down's syndrome), and affects approximately 7.5% of English-speaking children (Norbury et al., 2016). Solid mechanistic understanding of this condition is valuable not only from a theoretical standpoint, for instance in improving our understanding of typical brain function, but also for the purposes of providing effective programmes of support for affected children, many of whom face significant social, educational, and employment challenges. Dominant theoretical accounts of DLD are unanimous in assuming working memory capacity limitations, both in the central executive and verbal short-term memory subsystems defined in Baddeley and Hitch's (1974) model (e.g., Montgomery et al., 2019). This has motivated the development of programmes of intervention that aim to target working memory capacity and in doing so improve the child's language ability. In this talk, however, we present a radically different view: That working memory in DLD is not atypically capacity limited but is instead overloaded due to operating on speech representations with low separability. Under this view, apparent working memory task performance deficits are understood as the downstream consequence of low-level deficits in frequency discrimination.

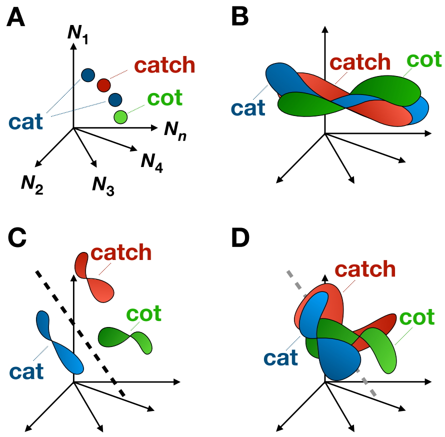
Our account is developed through computational simulations involving deep convolutional neural networks trained on spoken word spectrograms in which frequency information was either retained or degraded to mimic spectral processing deficits identified among some children with DLD (McArthur & Bishop, 2005). We simulated a speech recognition task in which 5000 recorded spoken exemplars were classified as one of 35 words. We monitored not only speech recognition accuracy and predictive probability and entropy (i.e., predictive distribution spread), but also used a recently developed framework known as mean-field-theory-based manifold analysis to assess; (i) the shape or *dimensionality* of the internal speech representations or 'manifolds' formed by the networks (see supplementary material, Figure 1), and (ii) *network classification capacity*; a proxy for executive control operationalized as the number of linearly separable word manifolds per artificial neuron, per network layer (Stephenson et al., 2020). This latter metric is appropriate as the retrieval of speech representations and inhibition of competitors within an activated cohort is a key feature of executive control.

We show that instantiating a low-level frequency discrimination deficit results in the formation of speech representations with atypically high dimensionality, and that classification capacity (i.e., executive control) is overwhelmed as a consequence of low representation separability (see supplementary material, Figure 1). These representation and control deficits underpin not only lower performance accuracy in a simulated spoken word recognition task (80% accurate clean input versus 55% frequency-degraded input), but also greater uncertainty even when making accurate predictions (i.e., predictive distributions with relatively high entropy and low maximum probability); a finding which we argue parallels the response delays and word finding difficulties commonly seen in DLD. Overall, our simulations illustrate how apparent working memory capacity limitations can emerge as the consequence of speech representation deficits, challenging the status of such limitations as an indispensable feature of causal theories of DLD.

Supplementary material

Figure 1

A manifold geometry view of speech representation deficits in DLD



Note. (A) the spoken words *cat*, *catch*, and *cot* in high dimensional space, with each axis (N_1 to N_n) illustrating the response of a single neuron in a population, in spikes per second. Two spoken instances of the same word, e.g., *cat*, will reside in a different neural response vector. (B) collectively, response vectors associated with any given word form a manifold. Manifolds of different words are tangled early in the auditory-linguistic pathway due to cellular responsiveness to low-level acoustic features. (C; a high-capacity system) manifolds are incrementally untangled throughout the auditory pathway, eventually supporting efficient discrimination and reducing attentional demand. (D; a low-capacity system) in DLD, a low-level auditory-perceptual deficit may mean that manifold untangling is protracted, leading to abnormally high-dimensional, high-order speech representations that are more difficult to discriminate and which therefore overwhelm attentional capacity.

References

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