# Title: An MEG evaluation of the dual-route model on language

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Marina Kilintari[1, 2*], Roozbeh Rezaie[1, 3], Shalini Narayana[1, 3, 4], Abbas Babajani-Feremi[1, 3, 4] and Andrew C. Papanicolaou[1, 3, 4]

- [1] University of Tennessee Health Science Center, Department of Pediatrics, United States
- [2] UCL, Department of Neuroscience, Physiology and Pharmacology, United Kingdom
- [3] Le Bonheur Children's Hospital, Neuroscience Institute, United States
- [4] University of Tennessee Health Science Center, Department of Anatomy and Neurobiology, United States

Introduction The study of the brain mechanisms of language has recently been given substantial impetus by the development of functional neuroimaging methods (see e.g. Price 2012 for a review). Such studies aim to provide new and more detailed accounts of the mechanisms underlying language production and comprehension. While the vast majority of these studies have not challenged the long-standing notion that all linguistic operations (phonological, semantic, syntactic) are supported by left hemisphere neuronal networks, a number of experimental findings (Hickok and Poeppel, 2007, 2015) raise doubts as to the validity of this generalization. To account for this evidence Hickok and Poeppel (Hickok and Poeppel, 2004, 2007, 2015; Poeppel et al., 2012) have proposed a model that deviates from the traditional one of left hemisphere language dominance, in two important points: First, they suggest, that like visual processing, linguistic processing involves two streams – a dorsal and a ventral, which are specialized for sub-lexical sound-motor (articulation) integration (or "speech-perception" according to their terminology) and for lexical "speech recognition" respectively. Second, their model posits three functionally distinct and successive phases in language processing: a) spectrotemporal analysis; b) phonological analysis; and c) speech-perception (dorsal stream) and speech recognition (ventral stream). The purpose of the present study was to assess the validity of this model. Specifically, to test its predictions regarding (a) the differentiation of semantic and articulatory processing in two separate cortical streams, (b) the lateralization of the effects and (c) the temporal sequence of the neuronal activity underlying these processes. To achieve this, we recorded and localized magnetoencephalographic activity in the context of two linguistic tasks whose successful performance inevitably required all 3 stages of linguistic processing and which had the potency to engage the specific brain areas that are posited by the model. Methods 8 adults with normal hearing were recruited for the study. Two experimental tasks (a) a syllable identification (and covert articulation) task and b) a word comprehension task were presented in a different random order to each subject. During these tasks, we obtained MEG data using a whole-head neuromagnetometer containing an array of 248 sensors. To identify the intracranial origin of the evoked magnetic fields (ERFs), the MAGNETIC flux distribution recorded simultaneously over the entire head surface at successive points was analyzed using a minimum norm estimate model (MNE) (Hämäläinen and Ilmoniemi, 1994) to obtain estimates of the time-varying strength of intracranial currents. All measures were made with respect to a prestimulus baseline, calculated as the mean level of activity over 250 ms prior to stimulus onset. Additionally, structural MR images were obtained on a 3 Tesla scanner (Siemens Verio) for the purpose of co-registering each individual's averaged reconstructed current time series with his/her corresponding MRI dataset. Results Spectrotemporal Analysis According to the model spectrotemporal analysis is bilaterally mediated and it is performed by circuitry in the dorsal part of STG. We tested the middle and posterior part of the dorsal STG as well as the transverse temporal gyrus (TTG) (Heschl's gyrus), which is known to be the area of the primary auditory cortex of the human brain. Irrespective of the task, spectrotemporal analysis was characterized by significantly greater activation of the TTG and pSTG in the left hemisphere as compared to the right ($p < 0.05$). Phonological Analysis The dual route model predicts that phonological analysis follows the spectrotemporal one and is taking place in the middle and posterior part of the superior temporal gyrus (STS), bilaterally. Accordingly, we examined whether the activation in this region was unilaterally or bilaterally distributed. We found that the mid-posterior STS exhibited no difference in activation

between the left and the right hemisphere for both linguistic tasks. Articulatory and Semantic Analysis The dual stream model holds that following the phonological analysis, the linguistic operations diverge into two broad streams: a temporal, mainly bilaterally organized, ventral stream which supports speech comprehension (speech recognition according to their terminology) and a strongly left lateralized dorsal stream, which supports sensory-motor integration (speech perception according to their terminology). Accordingly, we tested whether the suggested areas in the dorsal and ventral stream exhibit any lateralization effect. Our results did not support the main claim of the model that the third stage of linguistic operations engages differentially parts of the dorsal and ventral stream. Conclusion In conclusion, only few of the predictions of the Hickok and Poeppel dual route model of speech processing are confirmed by our data. The main hypothesis of the model that the third stage of linguistic operations engages differentially parts of the dorsal and ventral stream was not confirmed. However, since new technologies provide constantly new insights to brain mechanisms, one should be open to challenge any traditional belief and reassess established ideas. The brain mechanism that implements linguistic processing is far from being understood and any attempt to decipher it, even if it is radically different from any previous account, should be assessed carefully.

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* Correspondence: Dr. Marina Kilintari, University of Tennessee Health Science Center, Department of Pediatrics, Memphis, United States, m.kilintari@ucl.ac.uk