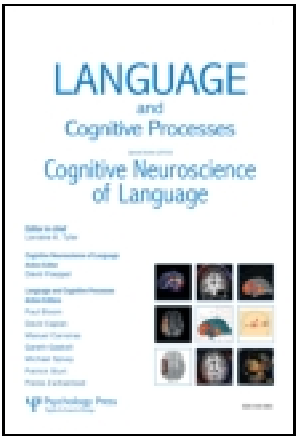

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Introduction to papers from the 5th Workshop on Language Production: The neural bases of language production

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Introduction to papers from the 5th Workshop on Language Production: The neural bases of language production

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The papers in this special issue of *Language and Cognitive Processing* on the neural bases of language production illustrate two general approaches in current cognitive neuroscience. One approach focuses on investigating cognitive issues, making use of the logic of associations/dissociations or the logic of neural markers as key investigative tools. The other approach has as its primary goal identifying the cognitive and computational functions performed by specific brain areas and understanding the underlying neurobiological mechanisms. The research described in the papers of this special issue applies these approaches to the study of fundamental questions concerning sign language, multilingualism, speech motor control and the interaction between speech production, and comprehension. We discuss how, in doing so, this research sheds light on the cognitive and brain mechanisms of language production.

Keywords: Language production; Speech production.

Until recently, the ever-expanding repertoire of neurocognitive methods had been more vigorously used in investigating language comprehension than language production. However, the increasing application of these methods

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to topics in language production makes this an appropriate moment to step back and consider the role and contributions of neural investigations in the area of language processing generally, and in language production, in particular.

Arguably, there are two general types of neural investigations of language, one primarily concerned with the cognitive aspects of language processing, the other with the neurobiological ones. The cognitively oriented approach involves using neural data to test cognitive hypotheses. Within this orientation, the neural data are used in ways that often parallel traditional behavioural measures such as response times, priming effects, etc., while, at the same time, taking advantage of neural constraints to strengthen hypothesis testing. In contrast, the primary objective of the neurobiologically oriented approach is that of understanding the cognitive/computational functions of the various brain regions and structures involved in language production. Understanding the language processing functions of the relevant neural substrates may be pursued not only for its intrinsic importance but also for its implications for therapeutic interventions, engineering, and other applications. It is important to note that, of course, cognitive and neurobiological objectives are not mutually exclusive, and that, in fact, there is often a fruitful interaction between them; nonetheless, we find the distinction a useful one in organising and evaluating the literature. The papers that make up this special issue of *Language and Cognitive Processes,* which were presented at the that *2008 International Workshop on Language Production,* exemplify these approaches and illustrate the promise and the challenges faced in the neurocognitive investigation of language processing.

OBJECTIVE: USING NEURAL DATA TO TEST COGNITIVE HYPOTHESES

In this context it is useful to first consider the logic by which neural data can be used in testing cognitive hypotheses. Two prominent approaches include what we will refer to as (1) association/dissociation logic and (2) the logic of neural markers. Association/dissociation logic is useful in testing hypotheses regarding shared or independent processes/representations. Essentially the reasoning is as follows: if processes/representations are independent, they may be instantiated in neural substrates that are spatially and/or temporally distinct. While functionally independent processes/representations do not necessarily require distinct neural substrates or signatures, the positive finding of neural dissociations can reasonably be considered as evidence favouring at least some degree of independence. As an alternative approach to testing cognitive hypotheses, the logic of neural markers attempts to leverage the fact that specific spatial or temporal neural response patterns can sometimes serve as a marker of a specific cognitive function of interest. This independently established marker of a cognitive function can then be used to test hypotheses regarding that function itself or its relationship to other functions. Both of these approaches are exemplified in papers in this special issue, and a brief summary of the papers here will serve to clarify and illustrate these points.

Association/dissociation logic

Multimodal brain mechanisms of language production

The study of sign language has been enormously important for furthering our understanding of the nature of the human language capacity. Thus, various lines of evidence have indicated that our innate language and grammatical capacities are not modality specific but, instead, are more abstract, expressing themselves not only in the aural-oral modality of speech but also in the visuo-spatial modality of sign (Emmorey, 2002; Petitto et al., 2000; Sandler & Lilo-Martin, 2006). Emmorey, McCullough, Mehta, Ponto, and Grabowski (this issue 2011) examined a question that is central to this line of inquiry, asking whether or not sign language can be reduced to pantomime. This question is key to the debate regarding the status of sign language as a bona fide language, with an important alternative hypothesis suggesting that sign is, instead, an elaborate pantomime system. While acknowledging that sign language may have had its origins in gestures, Emmorey et al. specifically examined the claim that sign has developed into a language system that is fundamentally different from gesture. While there are, of course, many experimental approaches one could pursue to addressing this issue, Emmorey et al. used positron emission tomography (PET) to investigate the dissociation/association of the neural substrates recruited by sign and pantomime. They reasoned that if sign and pantomime in deaf individuals involve different cognitive systems, their neural signatures should differ as well. Additionally, under the view that sign is not equivalent to pantomime one would expect that signing in the deaf would not produce the same neural activation pattern as pantomime in hearing individuals.

To test these predictions, deaf and hearing participants were shown photographs of objects during PET scanning. The deaf participants were asked to produce either the ASL sign for the verb associated with the object or to produce an object-related pantomime; the hearing participants were asked to produce object-related pantomimes. In a control condition, all participants made a yes/no gesture to indicate whether the depicted objects could be handled. Among other findings, Emmorey et al. reported that, for the deaf participants, the neural activity produced by verb signing yielded more activity in the left inferior frontal gyrus than that produced by the control condition. Critically, significant activation was not observed in this region for the deaf participants in a comparison of the neural activity generated by their pantomimed actions with the control condition. Consistent with this finding from the within-group comparison, significant results were also observed in this same inferior frontal region in an across-group comparison in which activation from the verb-signing condition in the deaf was compared to the activation generated by pantomime condition in hearing participants. On the basis of the dissociation of neural activation patterns for signing and pantomime, Emmorey et al. concluded that the production of ASL verbs and pantomime rely on at least partially distinct neural systems, thus providing support for the hypothesis that sign cannot be reduced to pantomime. In combination with findings from other research regarding the neural substrates of verb production in hearing participants, these findings indicate an association between the neural substrates recruited for verbs in spoken production and sign, such that verb retrieval recruits inferior frontal cortex regardless of the modality of language production. In this way, this work provides an example of the association/dissociation logic applied to neural data in order to address an important cognitive issue in language processing.

The logic of neural markers

The relationship between speech comprehension and production

A long-standing debate in the speech comprehension literature concerns the degree to which speech production plays a role in speech comprehension, presumably by providing a form of top-down feedback to the comprehension process. Poeppel and Monahan (this issue 2011) review the analysis by synthesis approach to speech recognition (Stevens & Halle, 1967) which proposes that a key component of recognition (analysis) is the active generation (synthesis) of the possible candidates of the speech input. Poeppel and Monahan revisit and recast this proposal in the contemporary context of research on predictive coding and Bayesian approaches to perception. An important component of the approach proposed by Poeppel and Monahan is that very early in the course of processing the acoustic speech signal, listeners automatically generate predictions regarding the identity of the input and, further, that these "acoustic" predictions are based the listeners' phonological knowledge. Thus, one source of evidence in support of this prediction-based approach to speech recognition would be the finding that listeners very rapidly detect violations of their acoustic predictions.

Based on a considerable empirical literature, many researchers have assumed that the M100 component measured by magnetoencephalography (MEG) and observed approximately 100 msec following the onset of an auditory event, constitutes a neural marker of early, automatic auditory processing. On this interpretation, changes within the M100 time window that can be related to violations of predicted phonological events would indicate the operation of a mechanism such as feedback that can bring higher-level phonological knowledge to bear on early perceptual processes. To evaluate this hypothesis, several MEG (as well as behavioural) studies have taken advantage of the fact that the presence of certain phonetic features can be highly predictive of the features of the upcoming segment. For example, nasalised vowels predict that the next segment will be a nasal consonant or, in word-final obstruent clusters, the voicing of the first obstruent predicts the voicing value of the upcoming one. These hypothesised operations can be examined experimentally as it is possible to manipulate acoustic material to create stimuli in which the expectations regarding the identity of an upcoming feature are either confirmed or violated. Poeppel and Monahan review MEG investigations by Flagg, Cardy, and Roberts (2005) and from their research group that examine the neural response to the presence of prediction-consistent vs. prediction-violating acoustic material. The findings of these studies show differences within the M100 window that are sensitive to at least certain of these prediction violations. Of course, the interpretation of these findings depends critically on the degree to which the characterisation of this neural marker as indexing early automatic processes is correct. Based on this interpretation, the findings reviewed by Poeppel and Monahan argue for early, automatic phonologically-based prediction, a sign of top-down feedback and a key component of analysis-by-synthesis hypothesis of language processing, at least in the form proposed by these authors.

Co-ordinating multiple languages in word production

Another important area of language research concerns the relationship among the processes and representations that support language production in the multi-lingual mind/brain. One of the consistent observations in this research area is that naming latencies are significantly longer and more variable in the second language (L2) than the first language (L1). Hanulová, Davidson, and Indefrey (this issue 2011) review research that has been directed specifically at understanding the stage of spoken work production at which this delay arises. Briefly, hypotheses vary as to whether these delays occur relatively early in word production (e.g., during conceptual processing or lexical retrieval), late in processing (during post-lexical phonetic processing) or are present throughout the production process. If there were some way of clearly identifying the various word production stages, one might then be able to characterise the locus of the L2 vs. L1 naming delay. This underscores the need for some kind of a marker of the different word production stages.

Hanulová et al. report on work that builds on the finding that the N200 evoked response potential (ERP) is sensitive to the inhibition or withholding of a behavioural response. For example, an N200 is observed when participants are asked to press a button if the name of a pictured object starts with a consonant and to withhold a response if it starts with a vowel (Rodriguez-Fornells et al., 2005). On this basis, Schmitt and colleagues (e.g., Schmitt, Münte, & Kutas, 2000) developed an experimental paradigm in which the N200 ERP serves as an index, or marker, of semantic and phonological processing stages in word production. They did so by manipulating whether the withholding of a picture naming response is dependent on a semantic or phonological attribute of the word to be named. By examining the latency of the N200 under these two different conditions, one can evaluate the specific timing of conceptual or phonological processes. That is, under these experimental conditions, the N200 can serve as a neural marker of conceptual and phonological processing stages of word production. The argument is that this provides a more transparent way of examining these processing stages than is possible by simply considering the effects of various experimental manipulations on overall naming latencies.

Hanulová et al. discusses that Guo and Peng (2007) made use of this paradigm to investigate the locus of the L2 naming delay by examining the time difference between the conceptual and phonological N200 effects in L1 vs. L2 picture naming. They found no differences between them and concluded that the source of the L2 naming delay is neither conceptual nor phonological but must, instead, be post-lexical. Hanulová et al. (this issue 2011) carried out a similar study using, in contrast to Guo and Peng (2007), a within-subject design. The results they obtained confirmed those of Guo and Peng (2007), as they too found no differences for L1 and L2 naming with regard to the temporal delay between the conceptual and phonological N200s. While these are a null effects (with their concomitant interpretive problems) they are specifically predicted by the hypothesis that L2 naming delays arise post-lexically and, in this way, they contribute importantly to the debate regarding the locus of interaction between L1 and L2 in spoken word production.

In sum, Poeppel and Monahan as well as Hanulová et al. provide examples of the neural marker logic applied to very different questions of language processing. In considering work that takes this approach, it is important to underscore that in all work applying the neural marker logic, the significance of the findings depends critically on the confidence with which one can assume that the neural marker does indeed index the cognitive process of interest.

OBJECTIVE: UNDERSTANDING THE NEUROBIOLOGY OF SPOKEN LANGUAGE PRODUCTION

A great deal of research involving neural data has at its primary goal understanding the cognition-brain mapping, in other words: understanding the cognitive/computational functions performed by specific brain areas and, in a complementary manner, identifying the neural substrates that subserve specific cognitive functions. Quite often the research proceeds as follows: a body of neural data provides information regarding the overall network of areas involved in performing a task such as picture naming or repetition, and then further work, guided by an understanding of the component cognitive computations, is directed at more specifically characterising the functions and relationships among the various regions within the overall network. Often, the cognitive functions are assumed to be sufficiently characterised and it is their neural instantiation that forms the focus of interest. An illustration of this approach is provided by Tourville and Guenther (this issue 2011).

The neural mechanisms of speech motor control

Tourville and Guenther (2011) state quite explicitly that the goal of their research programme "has been to improve our understanding of the neural mechanisms that underlie speech motor control" (page 953). In their case, a key component of the research is the development of a highly detailed computational model (DIVA) of the acquisition and production of the motor control of speech. The computational model instantiates an adaptive feedforward and feedback theory of speech motor control and also specifies the relevant neural substrates of the component computations. The modeling work serves to mediate between cognitive and neural research, integrating results of both in order to test and generate new hypotheses at both levels. The results of such studies may also have clinical and engineering implications.

Illustrating this approach is one of the specific additions to DIVA discussed by Tourville and Guenther (2011). In a series of fMRI studies, Tourville, Reilly, and Guenther (2008) and Golfinopoulos et al. (2010) investigated the neural substrates of the feedback components of the speech production process by comparing brain activity during speech production under conditions of normal and perturbed auditory and somatosensory feedback. These studies revealed, among other things, that the compensatory articulatory movements that speakers produced under the feedback perturbation conditions were associated with increased activity in right hemisphere ventral premotor area. This was interpreted as revealing that a critical function for this area involves feedback control. In this way, the neuroimaging investigation provided a better understanding of the cognitive/computational contributions of this brain region. As a consequence, DIVA was augmented through the addition of a right-hemisphere feedback control map that was then connected to other computational modules according to the results of additional analyses of the fMRI data and other available neural data. Furthermore, as an example of the clinical applications of the work, Guenther and Tourville pointed out that the work may well have implications for understanding and treatment of stuttering. Previous neuroimaging studies of speech production in stuttering (Brown, Ingham, Ingham, Laird, & Fox, 2005) had indicated increased activation in the same right hemisphere ventral prefrontal regions identified by Tourville and colleagues in the feedback perturbation studies. On that basis, Tourville and Guenther suggested that the data support the hypothesis that stuttering involves over-reliance on auditory feedback control due to perturbations elsewhere in the feed-forward components of the system.

SUMMARY AND CONCLUSIONS

We have suggested that cognitive neuroscience investigations typically have either cognitive or neurobiological objectives. Research with cognitive objectives typically involves using neural data to test cognitive hypotheses, while research with neurobiological objectives make use of known cognitive operations to better understand the computational functions of specific neural substrates or neural activity. As we have summarised, the papers in this special issues illustrate both types of research. We have also specifically proposed that in research with cognitive objectives different types of empirical logic may be deployed including, most commonly, either the logic of associations/dissociations or the logic of neural markers.

Of course, all approaches rely on specific assumptions and all have certain limitations. For example, in the context of the application of the logic of associations/dissociations, it is important to understand that the failure to find a dissociation of neural activation patterns does not necessarily mean that the cognitive operations of interest are not, in fact, independent in key respects. With regard to the use of neural markers of specific cognitive operations, the strength with which inferences can be drawn is determined by our degree of confidence that the markers have, in fact, been appropriately characterised. Similarly, efforts to understand the computational functions of specific neural areas are constrained by the adequacy and specificity of the cognitive theories that are adopted. Understanding these caveats is critical for deploying these techniques in a productive manner.

In sum, the papers included in this special issue illustrate some of the diversity of approaches taken in cognitive neuroscience as well the exciting possibilities that are currently available for the neural investigation of language production. Certainly, as the application of these approaches increases and new methodologies develop, our current understanding of the brain mechanisms underlying word production will undergo profound changes.

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