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# Lesions impairing regular versus irregular past tense production

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ABSTRACT

We investigated selective impairments in the production of regular and irregular past tense by examining language performance and lesion sites in a sample of twelve stroke patients. A disadvantage in regular past tense production was observed in six patients when phonological complexity was greater for regular than irregular verbs, and in three patients when phonological complexity was closely matched across regularity. These deficits were not consistently related to grammatical difficulties or phonological errors but were consistently related to lesion site. All six patients with a regular past tense disadvantage had damage to the left ventral pars opercularis (in the inferior frontal cortex), an area associated with articulatory sequencing in prior functional imaging studies. In addition, those that maintained a disadvantage for regular verbs when phonological complexity was controlled had damage to the left ventral supramarginal gyrus (in the inferior parietal lobe), an area associated with phonological short-term memory. When these frontal and parietal regions were spared in patients who had damage to subcortical ($n = 2$) or posterior temporo-parietal regions ($n = 3$), past tense production was relatively unimpaired for both regular and irregular forms. The remaining (12th) patient was impaired in producing regular past tense but was significantly less accurate when producing irregular past tense. This patient had frontal, parietal, subcortical and posterior temporo-parietal damage, but was distinguished from the other patients by damage to the left anterior temporal cortex, an area associated with semantic processing. We consider how our lesion site and behavioral observations have implications for theoretical accounts of past tense production.



## 1. Introduction

The aim of this paper was to investigate lesion characteristics of patients who have selective difficulties producing the past tense of English verbs. In English, past-tense forms are predictable (regular: walk–walked) or idiosyncratic (irregular: teach–taught) forms. The interpretation of such data has been the subject of an enduring debate which has implications for our theoretical understanding of the structure of the language processing system. Existing approaches differ in terms of their claims about the respective roles of morpho-syntactic, lexical, phonological, and semantic processes in the production of past-tense forms, and the relative contribution of these processes to regularity effects in aphasic past tense production. Explanations of selective past tense production impairments are developed from studies of the behavior and lesion sites of the affected patients.

According to one account of past tense production deficits, a disadvantage for regular verbs arises from a breakdown in the application of grammatical (morpho-syntactic) rules whereas a disadvantage for irregular verbs arises from a breakdown in the retrieval of whole lexical forms (Clahsen, 1999; Pinker, 1997; Pinker and Ullman, 2002; Prasada et al., 1990; Ullman, 2001a; Ullman et al., 1997). At the behavioral level, this dual-mechanism account predicts that a disadvantage for regular verbs will be associated with impairments in producing grammatical speech (agrammatism) whereas a disadvantage for irregular verbs will be associated with word-finding difficulties (anomia) (Miozzo, 2003; Ullman, 2001b; Ullman et al., 2005). However, according to an extensive review of the literature (Faroqi-Shah, 2007), there is limited evidence for this explanation of the currently reported patient data. A recent alternative to this account, which also attributes

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past tense production deficits to grammatical processes, argues that impairment to the morpho-syntactic system should affect both regular and irregular forms, as both have to be marked for tense during production (de Diego Balaguer et al., 2004; Faroqi-Shah and Thompson, 2004).

In contrast, a connectionist, single-mechanism account proposes that damage to the speech output system produces a disadvantage for regular verbs due to their relatively greater phonological complexity. A disadvantage for irregular verbs arises from a breakdown in the generation of divergent transformations that rely more heavily on a semantic network to overcome the pre-potent regular transformation (Daugherty and Seidenberg, 1992; Hoeffner, 1992; Joanisse and Seidenberg, 1999; McClelland and Patterson, 2002a,b; Plunkett and Marchman, n.d.; Rumelhart and McClelland, 1986; Woollams et al., 2009). From the connectionist perspective, selective difficulty with regular or irregular past tense production is expected to result from deficits in phonological or semantic processing respectively. Regular verbs are thought to place increased demands on phonological processing because regular past-tense forms tend to be more phonologically complex with more phonemes and/or offset consonant clusters than irregular forms (Bird et al., 2003; Braber et al., 2005; Lambon Ralph et al., 2005). Evidence for this perspective is also limited because there have been inconsistent reports of the degree to which selective difficulties in regular past tense production depend on phonological complexity (Bird et al., 2003) or not (Ullman et al., 2005). In addition, deficits in semantic processing have not always been found to produce selective impairments with irregular past tense production (Tyler et al., 2004) but see Patterson et al. (2006, p. 179).

In sum, whereas some accounts of past tense production focus on the importance of morpho-syntax and lexical retrieval, others focus on morpho-phonology and its interaction with semantics, although in both cases the evidence for an association between disturbances in more general language processes and specific past tense deficits has been mixed. To explore whether certain profiles of language difficulty were associated with selective impairments in past tense production in our patients, we considered: (i) lexical retrieval ability when producing the name of a single object in a picture; (ii) grammaticality of speech when describing a scene in a picture; (iii) the presence of phonological errors or dyspraxia during auditory word repetition; and (iv) semantic difficulties in auditory and written comprehension tests. The impact of phonological complexity was also assessed by considering how performance changed for a subset of regular and irregular verbs matched on this dimension.

With respect to the lesion sites associated with selective impairments in regular or irregular past tense production, the dual-mechanism account predicts that a disadvantage in producing regular verbs will be associated with damage to areas in the left inferior frontal cortex associated with syntactic processing (Grodzinsky, 2000; Pinker and Ullman, 2002; Tyler et al., 2002; Ullman et al., 2005) or procedural memory systems that subserve syntactic processes (e.g., in the basal ganglia (Ullman et al., 1997)). The same account predicts that patients with a disadvantage for irregular verbs will have lesions in temporal lobe areas associated with the retrieval of lexical representations from declarative memory (Jaeger et al., n.d.; Miozzo, 2003; Ullman, 2001b). Notably, however, the lesion sites expected on the basis of the dual-mechanism account (above) are similar to those considered to be important for the alternative connectionist account: i.e., a disadvantage for regular verbs will be associated with damage in phonological processing areas (e.g., left inferior frontal cortex) while a disadvantage for irregular verbs will be associated with damage in semantic processing areas (e.g., the left temporal lobe). It is therefore essential to consider which parts of the frontal or temporal lobes have been damaged. This requires an understanding of the functional anatomy of the language system that is emerging from functional imaging studies. For example, posterior middle temporal and temporo-parietal regions are associated with lexical retrieval and word recognition (Binder et al., 2009; Price, 2010) which are predicted to affect the retrieval of irregular verb forms under a dual-mechanism account (Jaeger et al., n.d.; Miozzo, 2003; Ullman, 2001a). The anterior temporal lobe is more specifically involved in semantic associations (Binney et al., 2010; Visser et al., 2010) that may support the production of irregular verbs under a connectionist account (Holland and Lambon Ralph, 2010; Patterson et al., 2001). This more precise functional-anatomical perspective has been considered in the functional imaging of past tense production in healthy individuals (Desai et al., 2006; Joanisse and Seidenberg, 2005; Oh et al., 2011) but is much more challenging when applied to the lesion literature because patients with selective past tense production impairments often have extensive frontal and/or temporal lobe damage (Bird et al., 2003; Braber et al., 2005; de Diego Balaguer et al., 2004; Laiacona and Caramazza, 2004; Lambon Ralph et al., 2005; Shapiro and Caramazza, 2003; Tsapkini et al., 2002). For example, despite the importance of inferior frontal regions in both the single- and dual-mechanism accounts of the data, there is only inconsistent evidence that a disadvantage with regular past tense production is associated with left frontal lobe lesions (Faroqi-Shah, 2007).

Naturally occurring brain damage, from stroke or degenerative disease, tends to include many different functionally distinct areas, not all of which will be related to the function of interest. One way around this challenge is to search for brain regions that are consistently damaged across a population of patients with the same type of selective past tense production impairment; and then to consider whether the common lesion sites are (a) not damaged in patients without the same impairment; and (b) located in areas of the brain associated with phonological, semantic or syntactic processing in functional imaging studies of language.

There are challenges to such lesion studies that might prevent us drawing useful conclusions. For example, there would be no consistency in lesion sites if the same selective deficit were caused by damage to different areas within a larger network in different patients. Moreover, a lesion site that was consistent for patients with the same selective deficit might also be observed in patients without the same selective deficit, if the latter had recovered their ability to produce past-tense forms following functional re-organization of the language networks. Critically, however, the impact of these challenges is to increase false negative results. They would not explain observations that there were lesion sites that were (a) consistently associated with selective past tense production deficits; (b) not observed in patients who did not have impaired past tense production; and (c) located in well-known sites of activation in functional imaging studies of language.

The robustness of any conclusions regarding the relationship between lesion site and behavior depends on whether the same findings can be replicated across multiple patients. Confidence in the conclusions is proportional to the number of patients whose lesion sites and behavioral profile are in accord with the proposed interpretation. In reality, it is difficult to systematically control for the location of brain damage that naturally varies from patient to patient; and it is time-consuming to conduct extensive behavioral assessments on each patient in order to understand specific lesion–symptom associations. We took a pragmatic approach by selecting a sample of 12 patients who had aphasic speech following a left hemisphere stroke. Although lesion site was not a selection criteria, our aphasic sample had a heterogeneous assortment of damage to frontal, temporal and subcortical structures. By mapping their lesions in standard space, we were able to test hypotheses about the importance of frontal and temporal lesion sites for regular and irregular past-tense impairments. When considered alongside the functional imaging literature, we were also able to generate new hypotheses that best explained all of our behavioral and lesion site data.