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Brain and Language 85 (2003) 527–530
Brain and Language
www.elsevier.com/locate/b&l

Commentary

The brain makes a distinction between hard and easy stimuli: Comments on Beretta et al.

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Accepted 3 February 2003

Abstract

The Beretta et al. study tested an invalid prediction concerning connectionist models of inflectional morphology and the study exhibits a confound between type of stimulus (regular, irregular) and processing difficulty (easy, hard) that invalidates their conclusions. Harder stimuli produced greater activation across a broader range of brain areas, as in previous studies, but the data have no bearing on the rules vs. connections debate.

1. Introduction

The Beretta et al. (2003) article purports to provide evidence bearing on the debate concerning dual-mechanism and connectionist accounts of inflectional morphology. The study exhibits two fatal flaws: first, a misconstrual of what the connectionist theory predicts, and second, a fundamental problem with the neuroimaging methodology. As a consequence the results they report are uninformative about the broader theoretical issues. Our goals in writing this response were to correct the misimpressions that might be left by a casual reading of their paper and to describe the problems with the study in a way that will help future researchers.

2. The theoretical flaw

Beretta et al. contrasted the dual-route approach (in which regular and irregular forms are processed by separate mechanisms thought to have distinct computational properties and brain bases) with the single mechanism connectionist approach (developed in articles such as Seidenberg & McClelland, 1989, and Joanisse & Seidenberg, 1999). They then formulated the hypothesis that any difference between regular and irregular forms (e.g., in pattern of brain activity) favors the dual-mechanism theory. We have heard this assertion before and need to explain why it is wrong. We already know that regular and irregular forms differ and do not need a neuroimaging study to prove this. Beretta et al. cite several of the relevant behavioral studies and wonder why, given the repeated demonstration that regular and irregular forms differ, the single mechanism theory has not been declared legally dead. The reason is simple: our theory does not actually make the prediction of no difference between regular and irregular forms. To the contrary, our models refute the claim that differences between regular and irregular forms implicate separate mechanisms.

Thus, of the following two statements:

(a) Regular and irregular forms are processed by the same mechanism.
(b) Regular and irregular forms produce the same pattern of results.

Our theory asserts (a), but Beretta et al. assume the fallacious (b). In brief, we assume a lexical network consisting computations between codes (orthographic, phonological, and semantic), and that the processing of all words occurs within this network. The network is a "single" mechanism in the sense that it is used to process all words, in contrast to some words being processed by one mechanism and some shunted to another.

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0093-934X/03/$ - see front matter © 2003 Published by Elsevier Science (USA).
doi:10.1016/S0093-934X(03)00065-8

Importantly, however, such networks do not yield the same performance on every item. Some are easier than others, owing to numerous factors such as consistency of the mappings between codes (e.g., spelling–sound; present–past tense), frequency, semantic complexity, and others that have been explored in models of both word reading and the past tense. This was the main point of our very first model, SM89, in which a single network produced different behavior for words with regular vs. irregular pronunciations. (Specifically, it produced the frequency × regularity interaction [LF irregular > LF regular differ, but HF irreg = HF reg] that has been observed in many studies of reading aloud; the same pattern also occurs in past tense generation, Daugherty & Seidenberg, 1995.) By Beretta et al.'s thinking, the differences in naming latencies between regular and irregular forms observed in such behavioral studies already implicated two separate mechanisms but this is exactly the logic that SM89 were at pains to demonstrate invalid.

In short, the question is not whether regular and irregular forms differ but why. We have taken the standard connectionist triangle model and begun to apply it to the past tense generation task (Joanisse & Seidenberg, 1999). The production of the past tense is a constraint satisfaction process that primarily involves phonological and semantic information (it can also involve orthography and experiment-specific strategies depending on how the study is designed). The regular past tense relies mainly on the strong phonological regularities in the mapping from present to past tense. The irregulars require more input from semantics, because the subject must access this information in processing a verb such as TAKE in order to produce the past tense TOOK.

Note that all words are processed through the same network; they differ insofar as the settings of the weights dictate how much a given type of information contributes to a given word. See Harm and Seidenberg (submitted); (available from http://lcnl.wisc.edu) for discussion of the division of labor between different components of a lexical network and how they jointly determine the best-fitting output in computing the meanings of words.

It follows from our view that patients with semantic impairments should be more impaired in generating irregular past tenses than regular, a prediction confirmed by Patterson, Lambon Ralph, Hodges, and McClelland (2001). Conversely, we predict that phonological deficits (associated, e.g., with Broca-type aphasia) should have a bigger impact on the generation of rule-governed forms, particular novel WUG-type forms, a prediction confirmed by Bird, Lambon-Ralph, Seidenberg, McClelland, and Patterson (in press).

In summary, the reason our theory is not dead is because it *accounts* for differences between regular and irregular forms (as well as intermediate, partially irregular forms such as SLEEP–SLEPT and WOLF–WOLVES) in terms of graded use of phonological and semantic information, not because it denies they exist.[1]

3. The methodological flaw

Beretta et al.'s study exhibits a methodological flaw that occurs so often in neuroimaging studies that we have given it a name: the difficulty matching error (DME). The problem is as follows: the experimenter wishes to examine brain activity associated with two types of stimuli (e.g., tools vs. animals or regular vs. irregular verbs). Differences between the conditions are interpretable in terms of the factor of interest (type of stimulus) only if the stimuli are equated across conditions in terms of processing difficulty. Words differ along many dimensions that affect how hard they are to process, not merely the one that motivates a given study. Numerous studies involving many tasks have shown that the relative difficulty—due to processing or attentional demands—influences patterns of brain activation (see, e.g., Carpenter, Just, Keller, Eddy, & Thulborn, 1999; Fiez, 1997), typically seen as an increased number of pixels activated, and increased activation levels, in frontal areas and with increased bilateral involvement. It is therefore essential to equate the stimuli for processing difficulty (e.g., by examining reaction time and error data), allowing differences in brain activity to be more confidently attributed to the variable of interest, as is now being done in many studies.

In the Beretta et al. experiment, the stimuli consisted of regular and irregular plurals and past tenses and their base forms. The properties of the stimuli and how they were selected are not adequately described. The three

[1] Beretta et al.'s discussion of our model is not accurate; they assert that the model showed no effect of phonological damage on regulars vs. irregulars but the findings are actually somewhat different and match up well with data from a recent careful patient study (Bird et al., in press). In brief, phonological damage has a consistent effect on nonword generalization (the "wug test"), as in models of spelling–sound correspondences. The effects on regular vs. irregular past tenses are more varied, as they are in patients. We ran our models many times, corresponding to many "patients." In 9 cases out of 50, phonological damage produced a 10% or larger impairment for regulars compared to irregulars; Bird et al. screened the same number of Broca-type (anterior) aphasics and found this pattern in 10 cases. Seven model cases produced the opposite pattern, with irregulars affected more than regulars. Ullman et al. claim that the regular < irregular pattern is more prominent than in our simulations, but they report data from only 1 Broca-type aphasic who could perform the past tense generation task (the other patients could only read the verbs aloud). There is also a phonological complexity confound in Ullman et al.'s stimuli such that the regulars were more complex than the irregulars. Bird et al. replicated their regular vs. irregular difference with their stimuli but show that the difference disappears when the stimuli are properly equated. Thus, the Joanisse and Seidenberg results actually closely fit the existing patient data.

relevant sentences in the methods section indicate only that the stimuli were matched on a measure of frequency; no descriptive statistics are provided (for discussion of issues concerning equating on word frequency, see Zevin & Seidenberg, 2002). Worse, the authors did not provide latency or on-line error data for the words in the different conditions; thus it cannot be determined if they were equated in processing difficulty. Previous studies of English indicate that lower frequency irregulars are harder to process than lower frequency regulars of matched frequency. The patterns of brain activation that Beretta et al. observed are highly consistent with the conclusion that their irregular forms also were more difficult than their regulars.

As the authors noted, irregulars produced greater overall activation than regulars (as measured, e.g., by number of voxels). This activity was diffuse, bilateral, and included several frontal areas, findings characteristically associated with increased task difficulty. Statistical tests within regions of interest yielded significantly greater frontal and bilateral activity for the irregular words compared to regulars; conversely there was no brain area for which the regulars produced significantly greater activation than irregulars.

This highly asymmetrical pattern indicates that one type of stimulus was more difficult than the other (the DME). With this confound it cannot be determined whether the effects were due to the variable of interest (the reg vs. irreg contrast), or other properties of the words. To make this concrete, imagine that the authors had instead compared their irregular stimuli to regular forms that were equally difficult (e.g., because they were lower in frequency). It cannot be assumed that the same regular–irregular differences would be obtained in this case.

The DME occurs far too often in neuroimaging studies. Often the difference between conditions with respect to processing difficulty is attributed to "working memory load" and taken as a discovery about the involvement of working memory in language processing. In such cases "working memory load" is just a term for "unknown differences between stimuli that affect processing difficulty" (MacDonald & Christiansen, 2002). The prescription is clear: to avoid the problem the conditions in an imaging study must include ones that allow comparisons between stimuli that are similar in processing difficulty.

In summary, what Beretta et al. have shown is that harder stimuli produce more brain activity than easy stimuli. It remains to be determined whether there are systematic differences between regular and irregular forms. If such differences are observed in a properly designed study, then the question is whether they support the assumption of separate, noninteracting lexical and rule mechanisms or merely the different contributions of semantics and phonology to irregular and regular forms, respectively.

4. About german inflection

We think that Beretta et al., like Marcus, Brinkmann, Clahsen, and Wiese (1995), Clahsen (1999), and others, have misanalyzed the fundamental nature of this system. For this brief discussion we will focus on the more widely studied German plural, but similar considerations hold for tense. The claim dating from Marcus et al. is that the regular plural rule is a low frequency default. The irregular plurals in German fall into a small number of phonologically based clusters (in our terminology, attractor basins). The regular rule is said to be a default that applies blindly to any form that does not fall into one of these clusters. Since the rule applies to relatively few words and connectionist nets are said to be sensitive only to word frequency, the rule is thought to be unlearnable by such nets.

There are many problems with this analysis (e.g., connectionist networks are not just sensitive to word frequency; they pick up on statistical regularities at multiple grain sizes), but the main one is that the regular rule is not a genuine default. A default rule is one that applies when other conditions are not met (e.g., the condition of finding an irregular form stored in memory). It follows that the properties of the words to which the rule applies are irrelevant, as Marcus et al. claim. This analysis ignores the fact that there are positive conditions that govern the application of the German plural rule. The conditions are both phonological and semantic: e.g., the rule applies to foreign words whose phonology deviates from standard German (e.g., BIKINI–BIKINIS), to words that have particular meanings (e.g., they are the names of people, like CHILD–CHILDS), and so on (see Marcus et al. for discussion). Thus, the formation of the plural in German is a classic constraint satisfaction problem driven by phonological and semantic information. Marcus et al. note that *neither* semantics *nor* phonology alone provides a basis for determining when to apply the rule but they fail to note that the *conjunction* of these types of information is highly constraining. This demands the same type of architecture proposed by Joanisse and Seidenberg, merely extended to represent the relevant semantic dimensions of German nouns.

5. Conclusions

Neuroimaging studies have the potential to provide critical evidence relevant to the rules vs. connections debate, but we have yet to see a study that does so. In addition to the issues raised above, future studies will need to address the following:

1. Is the relevant distinction rule-governed vs. exception? The dual-mechanism theory treats these as dichotomous but several facts contradict this: for

example, some irregulars pattern with regulars (e.g., HF ones); the formation of novel past tenses is affected by semantic (i.e., lexical) factors (Ramscar, 2002); there are intermediate cases like SLEEP–SLEPT, which are partly regular (the /t/ suffix is phonologically regular) and partly irregular (the vowel change in the stem). These phenomena are easy to account for in a single mechanism theory (see Haskell, MacDonald, & Seidenberg, in press; Ramscar, 2002) and harder to deal with in dual-mechanism theories. The crucial point is that imaging studies need to test theories which suggest other bases for grouping stimuli than the regular vs. irregular distinction.

2. What are the functions of the brain areas associated with the processing of different forms? One theory says they correspond to a lexicon and a rule procedure; the other that they correspond to semantic and phonological codes within the lexical network. These different claims might be distinguished by determining what other stimuli activate these areas. In addition, is there any consistency across studies with respect to which areas are activated by which types of stimuli?
3. The status of the other phenomena. There are now strong challenges to nearly every assertion about the English past tense that have been offered in support of the dual-mechanism theory (see, e.g., Haskell et al., in press; McClelland, Patterson, Pinker, & Ullman, 2002; Ramscar, 2002). Less is known about German and other languages but we expect similar developments to occur. Neuroimaging data need to be taken in the context of these other phenomena if a consistent, integrated theory is to be achieved.

Acknowledgments

We thank Marc Joanisse and Maryellen MacDonald for very helpful input. Our research on morphology is supported by NIMH Grant RO1-MH58723.

References

Beretta, A., Campbell, C., Carr, T. H., Huang, J., Schmitt, L. M., Christianson, K., & Cao, Y. (2003). An ER-fMRI investigation of morphological inflection in German reveals that the brain makes a distinction between regular and irregular forms. *Brain and Language, 85*, 67–92.

Bird, H., Lambon-Ralph, M., Seidenberg, M. S., McClelland, J. L., & Patterson, K. E. (in press). Deficits in phonology and past-tense morphology: What's the connection? *Journal of Memory and Language*.

Carpenter, P. A., Just, M. A., Keller, T. A., Eddy, W., & Thulborn, K. (1999). Graded functional activation in the visuospatial system with the amount of task demand. *Journal of Cognitive Neuroscience, 11*, 9–24.

Clahsen, H. (1999). Lexical entries and rules of language: A multidisciplinary study of German inflection. *Behavioral and Brain Sciences, 22*, 991–1060.

Daugherty, K., & Seidenberg, M. S. (1995). Beyond rules and exceptions: A connectionist approach to inflectional morphology. In S. Lima, R. Corrigan, & G. Iverson (Eds.), *The reality of linguistic rules*. Amsterdam: John Benjamins.

Fiez, J. A. (1997). Phonology, semantics, and the role of the left inferior prefrontal cortex. *Human Brain Mapping, 5*, 79–83.

Harm, M., & Seidenberg, M. S. (submitted). Computing the meanings of words in reading: Division of labor between visual and phonological processes. *Psychological Review*.

Haskell, T., MacDonald, M. C., & Seidenberg, M. S. (in press). Language learning and innateness: Some implications of compounds research. *Cognitive Psychology*.

Joanisse, M., & Seidenberg, M. S. (1999). Impairments in verb morphology after brain injury: A connectionist model. *Proceedings of the National Academy of Sciences (USA), 96*, 7592–7597.

MacDonald, M. C., & Christiansen, M. H. (2002). Reassessing working memory: A comment on Just & Carpenter (1992) and Waters & Caplan (1996). *Psychological Review, 109*, 35–54.

Marcus, G., Brinkmann, U., Clahsen, H., & Wiese, R. (1995). German inflection: The exception that proves the rule. *Cognitive Psychology, 29*, 189–256.

McClelland, J. L., Patterson, K., Pinker, S., & Ullman, M. (2002). The Past Tense Debate: Papers and replies by S. Pinker and M. Ullman and by J. McClelland and K. Patterson. *Trends in Cognitive Sciences, 6*, 456–474.

Patterson, K. E., Lambon Ralph, M. A., Hodges, J. R., & McClelland, J. L. (2001). Deficits in irregular past-tense verb morphology associated with degraded semantic knowledge. *Neuropsychologia, 39*, 709–724.

Ramscar, M. (2002). The role of meaning in inflection: Why the past tense does not require a rule. *Cognitive Psychology, 45*, 45–94.

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96*, 523–568.

Zevin, J., & Seidenberg, M. S. (2002). Age of acquisition effects in reading and other tasks. *Journal of Memory and Language, 47*, 1–29.

Further reading

McClelland, J. L., & Patterson, K. E. (in press). Rules or connectionis in past-tense inflections: What does the evidence rule out? *Trends in Cognitive Sciences*.