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Mapping dissociations in verb morphology

Aureliu Lavric, Diego Pizzagalli, Simon Forstmeier and Gina Rippon

Substantial behavioural and neuropsychological evidence has been amassed to support the dual-route model of morphological processing, which distinguishes between a rule-based system for regular items (*walk–walked*, *call–called*) and an associative system for the irregular items (*go–went*). Some neural-network models attempt to explain the neuropsychological and brain-mapping dissociations in terms of single-system associative processing. We show that there are problems in the accounts of homogeneous networks in the light of recent brain-mapping evidence of systematic double-dissociation. We also examine the superior capabilities of more internally differentiated connectionist models, which, under certain conditions, display systematic double-dissociations. It appears that the more differentiation models show, the more easily they account for dissociation patterns, yet without implementing symbolic computations.

There are various circumstances under which the perceived structure of the environment represents a mixture of consistent and relatively idiosyncratic input. Most of the well-documented instances of such input are language phenomena, such as tense and

plural formation, as well as reading and spelling. These domains have received unprecedented scrutiny over the recent years, because there are significant issues believed to be at stake, as exemplified by the following questions: does learning involve segregation of regular and irregular input and if so are rules abstracted explicitly in the process?

Dual versus single route models of English past-tense
Although it is beyond doubt that, if required, people are able to abstract rules, it is not clear to what extent human learning is rule-oriented. If one assumes that rule abstraction is an essential component of learning, a straightforward prediction would be that it is more likely to take place when rules are few and simple. A classical example, English past-tense formation, can be characterized by one simple morphological rule ('add suffix *-ed* to stem'), applicable to numerous items. By contrast, the regularities characteristic of some of the 160–180 exceptions are numerous and can only be applied to small groups of items (*blow–blew*, *throw–threw*, etc. or *sink–sunk*, *drink–drunk*, etc.)¹. A reasonable rule-based theory would have to be a dual-route system, in the sense that the rule component would have to be complemented by some sort of non-rule learning of exceptions. Pinker and colleagues^{1–3} proposed such an account. In order to explain the sub-regularities among irregular items, their model postulated that the learning of exceptions is an associative process, in which items undergoing similar transformations become closely related.

An alternative to the categorical distinction between regular and irregular English past-tense would be the view that English past-tense is a

quasiregular⁴ continuum of (phonological) correspondences between stems and past-tense forms. Such a perspective has been embraced by the proponents of neural-network, or connectionist, models of morphological processing, whose emergence changed earlier perspectives dramatically. Connectionist systems are pattern associators made of neuron-like units, which directly map patterns of input (e.g. verb stems) onto patterns of output (e.g. past-tense forms). Although the distributed character of representations and the homogeneity of computational mechanisms are viewed as their fundamental properties, some networks do show various degrees of internal differentiation (e.g. architecturally segregated representations of orthography, phonology, semantics, and so forth^{5,6}, or the use of distributed and localist representations within one network⁷). Such networks are hereafter referred to as 'non-homogeneous' networks. Yet, even undifferentiated nets (hereafter referred to as 'homogeneous') are able to learn divergent input–output mappings through gradual retention of statistical properties of the input–output structure in the connections between units (weights).

‘...homogeneous connectionist models [of English past-tense] have been quite successful in accounting for behavioural evidence initially thought to support the dual-route theory...’

Homogeneous network models of English past-tense^{8–10} not only provided a concrete implementation of an associative mechanism able to learn irregularities, they crucially demonstrated that undifferentiated, single-route systems can learn all past-tense mappings, regular and irregular, without using rules. Furthermore, single-route models have been claimed to be more biologically plausible, because their multidimensionality and homogeneity parallel the microstructure of the brain¹¹.

In addition to being able to learn different mappings, homogeneous connectionist models have also been quite successful in accounting for a significant body of behavioural evidence initially thought to support the dual-route theory. It is important to discuss what made homogeneous models compatible with evidence that differentiated between regular and irregular items. As will become evident later, the same theoretical principles have been used to account for neuropsychological dissociations.

Behavioural dissociations

A list of differences between regular and irregular past-tense, claimed to support the dual-route model, would start with the advantage that regulars have both in terms of speed and accuracy of processing. In other

words, regular past-tense forms are generated faster (Prasada, S. *et al.*, pers. commun.; Ref. 12) and they are less prone to error¹³. Furthermore, most of the errors with irregulars are the so-called overregularizations (*seek–seeked*, instead of *seek–sought*). An interesting developmental phenomenon, referred to as the U-shaped acquisition curve, represents the abundance of overregularization errors with some irregular past-tenses after an initial stage in which children produce them impeccably¹⁴. Additional data are provided by the relationship between how frequently individual verbs are used and the efficiency of their processing. Irregulars show large frequency effects and regulars show little or no effects (Prasada, S. *et al.*, pers. commun.). Similarly, in paradigms requiring participants to judge the ‘goodness’ of past-tense forms, such judgments correlate with frequency for irregulars, but not regulars¹⁵. The above observations can be subsumed under two general points: (1) regulars are processed better; (2) a regular item is processed easily even if the retrieval of its individual features is not perfect. The dual-route model accounts for these conclusive points by invoking the regular/irregular dichotomy. As it turns out, this dichotomy is not the only factor able to explain both (1) and (2).

One-way dissociations, ‘defaults’ and consistency English past-tense displays an overwhelming numerical advantage for the regular pattern, i.e. the regular type is represented by more items and, thus, said to have a higher ‘type-frequency’. Hence, it has been claimed that the phonological mapping from stem to past-tense is more consistent for the regulars^{10,16}. Homogeneous networks are, by design, sensitive to such statistics and it was shown that novel past-tenses generated by networks tended to be regular whenever novel stems were not similar to existing irregulars, which mimicked the ‘default’ observed in human data¹⁰. Furthermore, the presence of irregular sub-regularities (*sink–sunk*, *drink–drunk*) in the training corpus influences regular default behaviour in networks⁹.

Similarly, random damage to homogeneous networks results predominantly in the disruption of irregular past-tense, but not in simulations using artificial input in which irregulars are highly consistent¹⁷. Thus, the statistical and phonological structure of English past-tense predicts systematic one-way dissociations in homogeneous networks with a processing advantage for regulars¹⁶. However, empirical data indicate that low-frequency and low-consistency defaults are also possible. The example of German noun plural *–s* has been intensely debated^{3,18,19}, but other cross-linguistic, as well as historical, evidence of the existence of low-frequency defaults seems rather persuasive^{20,21}. Their low type-frequency, combined with phonological inconsistency in some of them, makes them the least likely candidates for generalization in homogeneous systems. One such network model²⁰ resorted to

Aureliu Lavric*
Dept of Psychology,
University of Warwick,
Coventry, UK CV4 7AL.
*e-mail: A.Lavric@
warwick.ac.uk

Diego Pizzagalli
Laboratory for Affective
Neuroscience, Dept of
Psychology, University of
Wisconsin-Madison, USA.

Simon Forstmeier
Darmstadt University of
Technology, Germany.

Gina Rippon
Dept of Psychology,
University of Warwick,
Coventry, UK, and
Neurosciences Research
Institute, Aston
University, UK.

Box 1. Electrophysiological studies of regular/irregular morphological processing.

A number of studies have used ERPs, in which scalp electrophysiological recordings were time-locked to the presentation of words (verbs or nouns). ERP studies of morphological processing in English^{a,b}, German^{c,d} and Italian^e, all found differences between regular and irregular items. There is only one study that did not report such differences^f; however, the exclusively descriptive level at which these results were presented precludes us from further discussing its outcomes. All the above-mentioned studies used waveform analysis, which compares patterns of the ERP waveform (components) across conditions. Regular versus irregular differences in one ERP component – Left Anterior Negativity (LAN) – were found in studies of English^b and German^{c,d} verb morphology. These studies used violation paradigms, which compared ERPs corresponding to correct and incorrect past-tense forms separately for regular and irregular items. Incorrect versus correct irregulars, but not regulars, elicited a LAN. LAN was also found in response to incorrect versus correct irregular plurals in German^d; this study also found a N400-like deflection in response to incorrect versus correct regular plurals. A widespread negativity at a later latency was found in response to incorrect (regularized) versus correct irregular, but not regular, verbs in Italian^e.

At least two studies used priming paradigms and also revealed differences between regular and irregular items. Thus, in a study where German verbs were preceded either by themselves or their infinitives, primed regulars elicited a more positive wave in the N400 and post-N400 range; primed

irregulars resulted only in a late positivity⁹. Similarly, in a recent study in which English verb stems were either preceded or not preceded by their past-tense, primed regular items showed a reduction in the N400 amplitude, whereas primed irregulars elicited no statistically reliable effect^a.

Although ERP waveform analysis is a widely-used analytical tool, the distinguishing criteria for the identification of ERP components can be variable. More importantly, ERP waveforms represent electrical potentials recorded from the scalp, not directly from the brain. Source localisation algorithms are needed to infer which cortical regions were involved in the generation of the signals measured at the scalp.

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hard-wiring the 'default' suffix in order to simulate the low-frequency generalisation from old English.

Electrophysiological studies

Box 1 summarizes the outcomes from a substantial corpus of ERP studies of verb and noun morphology^{22–27}. These studies provide cross-linguistic evidence of differentiation between regular and irregular morphology. Furthermore, the similarity of the ERP features (Left Anterior Negativity) in German participles and noun plurals^{22,23} is a remarkable finding, considering the differences in type-frequency between regular participles and regular (–s) noun plurals. However, the precise interpretation of the functional significance of ERP features from these studies is not always straightforward. Thus, Penke *et al.*²² proposed that the Left Anterior Negativity (LAN), found in response to incorrect versus correct German participles, reflects morphological decomposition of the regularized (suffixed) irregular participle. Although the literature undoubtedly shows that LANs are often associated with morpho-syntactic structure building²⁸, there is also a growing body of studies that found LANs in response to increased working memory load²⁹. It is entirely conceivable that there simply might be different LANs, but this issue still remains to be clarified.

The ERP priming studies (see Box 1) show a consistent picture of differences between regulars and

irregulars in English and German^{24,25}. The N400 is one of the most extensively studied ERP components, localized to the temporal lobe, with a large number of studies relating the magnitude of this component to the amount of semantic processing³⁰. A reduction in what appears to be the N400 ERP component was observed in regular, but not irregular priming. Homogeneous models can only predict such differences based on phonology (better phonological priming for regulars), as it has been demonstrated that the network hidden unit representation of stems is more similar to that of past-tense forms for regulars³¹ and the degree of overlap between such representations correlates with priming in the network³². However, phonological priming cannot explain the ERP effect, as no N400 reduction was observed in either the phonological or nonce priming conditions. Given the above-mentioned results with N400, the authors seem justified in interpreting the reduced N400 in regular priming in terms of more lexical overlap between the regular stem and past-tense, as opposed to the irregular stem and past-tense.

Neuropsychological dissociations

A number of dissociations between regular and irregular English past-tense morphology, as a consequence of developmental disorders^{33–36} or brain damage^{37–41}, have been debated (see Box 2). A neural-network account based on perceptual salience⁴² was

Box 2. Clinical dissociations of past-tense processing.

Neuropsychological evidence of dissociations has been obtained from a number of clinical populations. Developmental disorders such as Specific Language Impairment (SLI) and Williams' syndrome, were associated with selective regular and irregular past-tense deficits, respectively^{a-c}. However, other studies found no clear-cut dissociations in Williams' syndrome^d and there have been attempts to explain impairments of regular morphology in SLI as a consequence of phonological deficits^e.

Double-dissociation patterns were also reported in individuals with neurological disorders [Parkinson's disease (PD) versus Alzheimer's disease (AD)]^f or brain injury (left frontal versus left temporal or temporo-parietal damage)^{f,g}. PD and left-frontal lesions were associated with predominant disruption of regular past-tense, whereas AD and left temporo-parietal lesions were showed to result in prevalent irregular depletion. Importantly, these double-dissociative patterns were found in a variety of paradigms, such as past-tense production, reading, and judgement^h, as well as in priming designs^g. On the basis of these results, regular and irregular morphology was linked to activity in frontal-striatal and in temporo-parietal areas, respectively^f. It was proposed that the former is associated with procedural, rule-based memory and the latter with declarative memory^{f,h}. However, some evidence is inconsistent with this anatomical model. Thus, a recent study of German participle in patients with anterior lesions found irregular participles more impaired than the regular participlesⁱ.

Clinical double-dissociations of regular versus irregular noun plurals in German have also been reported^j. Double-dissociative patterns were present with the *-s* plural versus other plurals. The *-s*

plural is considered by some authors to be a default^k, despite its low frequency and low phonological consistency. The dissociation between the *-n* masculine and the phonologically predictable *-n* feminine plural, and the susceptibility of the former, but not the latter, to frequency effects, was taken to indicate that *-n* feminine might be processed by rule, similarly to the *-s* plural^l.

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developed as an attempt to explain regular past-tense deficits in English associated with Specific Language Impairment (SLI)^{33,34}. In addition to other differences, English regular and irregular verbs happen to show discrepancies in the perceptual salience of the phonological change from the stem to the past tense (e.g. *fly–flew* versus *talk–talked*), owing to the low perceptual salience of the final phonemes in the regular past-tense- /t/ and /d/. Disruption of the network's phonological representation led to a large number of omissions, characteristic of SLI⁴³. However, despite over-regularizations (*steal–stealed*) being rare in SLI, the network showed a significant tendency to over-regularize.

A more general problem of the perceptual salience account is the following. Because it regards the impairment of regular forms as an impairment of less salient (*walk–walked*) as opposed to more salient (*steal–stole*) changes in irregular past-tense formation (with very few non-salient exceptions, e.g. *send–sent*), it predicts that irregulars should be less disrupted. Yet, as recent evidence suggests, SLI individuals do not seem better at generating existing irregulars as compared to regulars. Instead, they are able to produce novel irregular (*crive–crove*), but not regular (*plam–plammed*) forms³⁴.

With regard to clinical double-dissociations, a more general approach within the connectionist

framework was to treat them as stochastic processes and determine whether totally undifferentiated (homogeneous) networks could mimic such phenomena^{44–46}. Because the magnitude of selective disruptions varies in patients, it does not seem unreasonable to think of clinical dissociations as random lesions to homogeneous networks. Such random lesions are claimed to sometimes, albeit rarely, result in double-dissociative patterns^{44,45}. However, it has been shown that double-dissociations in homogeneous networks are largely an artifact of scale⁴⁶. These authors argued that the likelihood of regular pattern disruptions and, hence, of double-dissociations, would be extremely small in fully distributed, large scale networks, where the contribution of individual units to the network performance is negligible. In contrast, small networks, which are less biologically plausible, tend to show such dissociations.

There have been attempts to prove the contrary, by introducing item frequency into the original simulations of Bullinaria and Chater⁴⁶, which resulted in sporadic, rare, double-dissociation occurrences⁴⁴. Nevertheless, Bullinaria and Chater's simulations were intended to indicate the general trend (i.e. double-dissociations become less likely when network size increases) and should not be taken as an attempt to test a network of a biologically

plausible size. In fact, the 600-hidden-unit network they used is likely to be immeasurably small in biological terms. Finally, the stochastic approach to double-dissociations would not be able to explain double-dissociations that are unequivocally systematic (e.g. in neurologically-intact subjects), as homogeneous networks, by definition, do not compartmentalize into spatially predictable patterns.

Systematic double-dissociations in brain-mapping studies

It was hoped that brain-imaging technology would provide decisive insights. The first brain-imaging study of past-tense⁴⁷ has generated intense discussion¹⁶. At least some criticisms appeared justified; that is, with respect to the use of blocked presentation of regular and irregular items, dictated by the relatively low temporal resolution of imaging technologies. The presentation of predictable sequences of regular items can have large confounding effects, owing to ad-hoc inference by participants as well as inter-item priming. Subsequent brain imaging studies, employing both PET⁴⁸ and fMRI⁴⁹ attempted to overcome this problem, by either intermixing imperfect and participle forms in German or presenting shorter blocks of regular/irregular items. Despite these efforts, the grouping of items remained quite obvious. Because of that and the drawbacks in the analytical procedures the outcomes from neuroimaging studies are difficult to interpret.

By contrast, ERPs, with their practically unconstrained temporal resolution, allow more flexible designs (e.g. intermixing regular and irregular items during presentation), and provide additional information on temporal dynamics. As we saw earlier, previous ERP studies of morphological processing used waveform analysis, which has limits in terms of anatomical localisation. In a recent ERP study (Lavric *et al.*, unpublished data), we used an objective, mathematically sound procedure to select the wave segments for statistical analysis⁵⁰, as well as electromagnetic tomography (LORETA)^{51,52}, both described in Box 3, to localize the scalp-recorded potentials in the cortex⁵¹⁻⁵⁵.

It is also worth mentioning that our study used a past-tense production paradigm, rather than a violation or a priming design used in previous ERP studies. The advantage of past-tense production is that it compares the conditions directly, rather than via the baseline, and embodies precisely the process implemented in connectionist models. Participants were presented with the verb stem and instructed to think of the corresponding past-tense. After a delay of 900 ms, participants were asked to verbalize this past-tense. This delay in verbalization was introduced to reduce the amount of ERP contamination and it was practiced prior to the ERP data collection. The results showed greater activity in right frontal areas for regular items, and in left temporal areas for irregular items (see Box 3, Fig. 1).

A recent magnetoencephalographic (MEG) study of English past-tense production, which used an alternative source-localization method (dipole modelling), reported similar results: at virtually the same latencies as in our study, regular items were associated with left-frontal and left temporo-parietal activity, whereas irregulars were associated with left temporo-parietal activity exclusively⁵⁶. There are some differences between the outcomes of the two studies, e.g. some divergence in the lateralization of the frontal activity in response to regulars. However, one should also be aware of the technical differences between the localization analyses used in the two studies (see Box 3).

Double-dissociations in non-homogeneous connectionist models

A distinct development within the connectionist framework has been to model systematic and neuroanatomically predictable double-dissociations⁵, which is of particular relevance in the context of the brain-mapping dissociations described above. In connectionist investigations it was shown that systematic and localized double-dissociations can be simulated if:

- (1) the network operates with more than one input dimension (e.g. orthographic and semantic⁵)
- (2) different dimensions are distinguished in the network's architecture
- (3) the input is differentiated (some items are more predictable) on at least one of the dimensions.

These conditions involve a certain degree of non-homogeneity, recently implemented in the past-tense domain by Joanisse and Seidenberg⁶: the network contained distinct clean-up levels corresponding to different types of information, phonology and semantics. The double-dissociative logic here is the following: if regular past-tenses are more predictable from their stems than irregular past-tenses from their stems, eventually regulars would be more dependent on the phonological representations in the network, whereas irregulars would have to rely more on their semantic, as compared to phonological, representations. The differentiation built into the network allows it to perform differently as compared to entirely homogeneous nets: providing the 'right' statistical and phonological structure of the training corpus, this model would, in principle, be able to parallel the systematic ERP and MEG double-dissociations presented earlier.

But does English past-tense have the 'right' structure? When the network simulated clinical double-dissociations⁶, phonological damage resulted in selective deficits with novel verbs, which is consistent with patient data, but not in selective impairments with regulars, which patients also show³⁹. In fact, when verbs were well equated for frequency, phonological damage led to more irregular than regular disruption. Only severe damage to the phonological compartment lead to a distribution of impairments, which included instances of disruption

Box 3. Principles and applications of space-oriented ERP analyses.

Scalp recordings of brain electrical activity offer non-invasive access to mental processes with millisecond time resolution. To draw conclusions about the spatio-temporal organization of these processes, analyses that can distinguish between the activity of different neural populations are required. As an initial step, 'space-oriented' ERP analysis treats the data as series of relatively stable spatial field distributions^a. At each moment in time, the distribution of the brain electrical activity across the scalp furnishes crucial information about the spatial pattern of momentarily active neuronal populations, and thus about the brain's functional state. A data-driven segmentation procedure^a can be used to determine the start and end times of such spatial field distributions.

Subsequently, in order to achieve greater anatomical specificity, source-localization algorithms can be employed, of which the most frequently used are dipole models^b and scalp current density models^c. Some dipole models assume the number of generators, whereas scalp current density models assume that generators are situated at equal depth from the scalp. Low Resolution Electromagnetic Tomography (LORETA, see Fig. 1)^d, a method that computes the intracerebral current density, is based on the more realistic assumption that neighbouring neurons will have similar magnitudes and orientations, an assumption that has received substantial support from animal single unit recordings^e. Fig. 1 shows the cortical loci where more activity was found for regular (right frontal areas) and irregular (left temporal areas) conditions, starting as early as 288 ms after stems were presented on the screen. This was a reliable result, which emerged in different LORETA analyses performed in the study.

LORETA has been physiologically validated in a variety of paradigms, including investigations of basic visual and

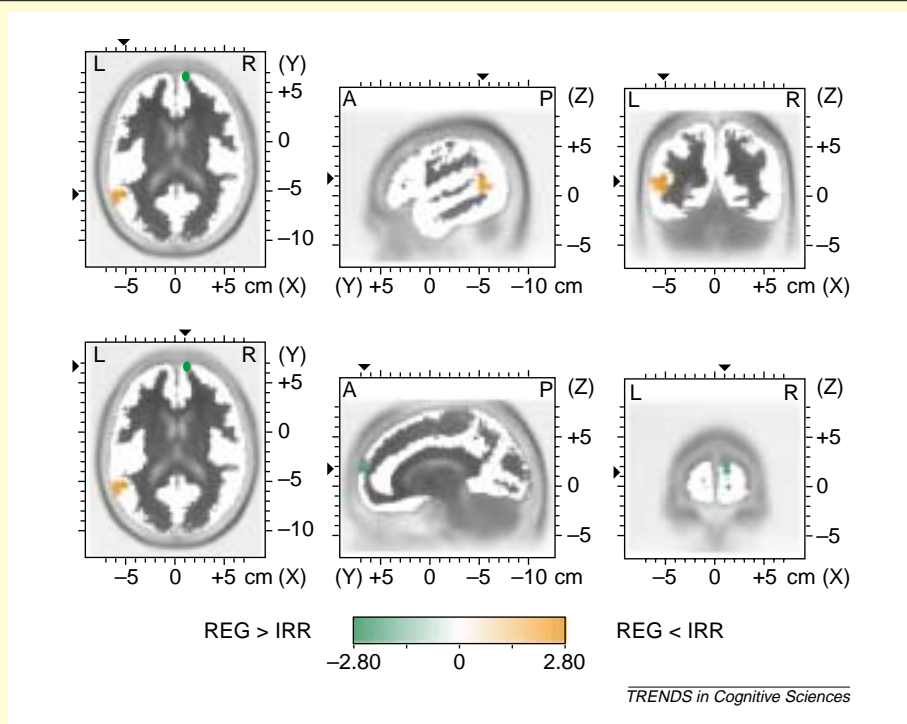


Fig. 1. LORETA results from an ERP study of English past-tense production (Lavric *et al.*, unpublished data). Images of statistically significant voxel-by-voxel LORETA t-tests comparing 3-D intracerebral distributions of current density elicited by irregular verbs and regular verbs in the time-window between 288 and 321 ms post-stimulus. Axial (head seen from above, nose up, L = left, R = right), sagittal (anterior part of the head to the left), and coronal brain slices are shown (left to right) at the level of maximal differences between the two verb conditions. Relatively higher LORETA activity for irregular verbs is shown in orange, for regular verbs in green (see calibration). LORETA's cortical solution area is shown in white. Black triangles show the locations of extreme t values. Coordinates in mm: origin at anterior commissure; (X) = left (-) to right (+); (Y) = posterior (-) to anterior (+); (Z) = inferior (-) to superior (+) (Ref. g).

auditory processing and cognitive tasks tapping specific brain regions as assessed independently in functional hemodynamic imaging studies^f. There is also recent evidence from several independent groups for cross-modal validation where LORETA localization was consistent with MRI, PET, fMRI and electrocorticography from subdural electrodes^f.

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of regulars compared to irregulars (though the proportion of such instances relative to the opposite pattern was not reported). Although this can be taken as a suggestion that regulars and irregulars are not sufficiently different phonologically to differentially rely on the phonological attractor network, further investigations are needed to clarify this supposition.

Nevertheless, recent data from German aphasic patients⁴¹ (see Box 2) indicates various patterns of double-dissociations of German noun plural, which would be difficult to explain in terms of phonological versus semantic deficits. For example, one patient showed an intact *-s* plural (low-frequency, low phonological predictability), but had deficits with the

Questions for future research

- Can recent developments in neuroimaging techniques and innovations in associated analytical procedures make them more useful for studying morphological processing?
- What would be revealed in electrophysiological studies of other language phenomena, also described as quasi-regular; for example, derivational morphology?
- Random lesions to homogeneous models of English past-tense revealed that the vast majority of dissociations involved prevalent disruption of irregulars, which also represents an implicit prediction that the vast majority of English-speaking patients with impairments of past-tense processing should encounter problems with irregulars. How is this supported by data?
- Comparative analysis of clinical data on morphological phenomena in different languages can be of particular interest. What would such investigations show?
- Can empirically-derived quantitative analytical tools (e.g. measures of phonological distance), similar to the ones in word recognition literature, be developed for assessing more precisely the impact of phonological similarity in morphological processing?
- Will neural-network models need further internal differentiation in order to provide a better account for extant data? There appear to be many options with regard to concrete implementations of such differentiation, so what criteria should dominate in the selection of most plausible models?

rest of plurals, some of them much more frequent and phonologically predictable. The connectionist account discussed above would explain this as a result of phonological damage, which would affect the consistent items. However, among the impaired plural patterns, the ones that were highly phonologically predictable (*-n* feminine) were not more affected than the less phonologically predictable ones (e.g. *-n* masculine) in any of the patients in this study, including the one mentioned above.

Differentiating computations

The non-homogeneous model presented earlier introduce differentiation at the level of input–output dimensions (e.g. phonology versus semantics), but within such networks there is only one type of representations (distributed) and one learning procedure. A further departure from homogeneity in connectionist models of morphology has been represented by differentiation at the computational level. Thus, two learning procedures (one performing fast, ‘one-shot’ learning and one-incremental learning) were implemented in a modular connectionist network, constructed to account for double-dissociations of German participle and the acquisition of plural^{57,58}.

A different approach was to employ a constructivist dual-representation model (containing distributed input and gradually-built localist hidden-layer representations) for simulating English past-tense and German participle dissociations^{7,59}. These models found it relatively trivial to master

systematic and ‘anatomically specific’ double-dissociations, yet without implementing explicit rules. The modular network also dealt satisfactorily with some low-frequency generalisations (the weak declension). Furthermore, the routes on which regular or irregular items depended preferentially, were not encapsulated, they contributed to processing of both types of items.

All this indicates that systematic brain-mapping double-dissociations, such as the ones discussed earlier, may indicate considerable differentiation in processing regulars and irregulars, but do not imply symbolic processing. It can be argued, however, that both the modular and the constructivist models have a pre-specified dual-mechanism character, given by the built-in architectural distinction between a route that retains only the most general input–output mappings and a route that is more sensitive to individual patterns.

Unfortunately, relatively little detail is available on simulations involving these models. They would also have to match homogeneous models of morphological processing in the range of behavioural phenomena accounted for.

Another critical issue is whether they would be capable of simulating specific patterns of clinical double-dissociation, without implausible built-in constraints, such as the hard-wired verb classes in the constructivist model. For example, it has been claimed that abnormal patterns of activity in the basal ganglia are associated with particular types of impairment of the regular past-tense: decreased activity leads to unmarked regular past-tense forms (*walk–walk*), increased activity leads to double-suffixation (*walk–walkeded*)³⁹. The dual-route account for such errors is that unmarked forms would represent the failure of suffixation and double-marked forms would correspond to double-suffixations. It is unlikely that such specific errors can be explained without resorting to some sort of morphological representations.

Conclusion

Substantial evidence from ERP components analysis and recent brain-mapping evidence of systematic double-dissociation in neurologically intact individuals points to limitations in homogeneous connectionist accounts of morphological processing. Although differentiation at the level of information dimensions (e.g. phonology versus semantics) opens a possibility for such models to show ‘anatomically specific’ dissociations, this only occurs in special circumstances, which are rarely met. Differentiation of representations and learning procedures within the same network significantly improves its ability to display systematic double-dissociations in the absence of symbolic processing. However, it can be argued that these models have a built-in duality of mechanisms, which predictably dissociate for regulars and irregulars. Finally, certain clinical data are still difficult to explain without resorting to morphological representations.

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