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Introduction

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Author for correspondence:
Dorothy V. M. Bishop
e-mail: dorothy.bishop@psy.ox.ac.uk

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When words fail us: insights into language processing from developmental and acquired disorders

Dorothy V. M. Bishop[1], Kate Nation[1] and Karalyn Patterson[2]

[1]Department of Experimental Psychology, University of Oxford, 9 South Parks Road, Oxford OX1 3UD, UK
[2]Clinical Neurosciences, University of Cambridge, Herchel Smith Building, Forvie Site, Robinson Way, Cambridge CB2 2PY, UK

Acquired disorders of language represent loss of previously acquired skills, usually with relatively specific impairments. In children with developmental disorders of language, we may also see selective impairment in some skills; but in this case, the acquisition of language or literacy is affected from the outset. Because systems for processing spoken and written language change as they develop, we should beware of drawing too close a parallel between developmental and acquired disorders. Nevertheless, comparisons between the two may yield new insights. A key feature of connectionist models simulating acquired disorders is the interaction of components of language processing with each other and with other cognitive domains. This kind of model might help make sense of patterns of comorbidity in developmental disorders. Meanwhile, the study of developmental disorders emphasizes learning and change in underlying representations, allowing us to study how heterogeneity in cognitive profile may relate not just to neurobiology but also to experience. Children with persistent language difficulties pose challenges both to our efforts at intervention and to theories of learning of written and spoken language. Future attention to learning in individuals with developmental and acquired disorders could be of both theoretical and applied value.

1. Introduction

The brain is not a homogeneous mass. The effect of a focal injury will depend crucially on which part of the brain is involved. Damage to certain regions of the left hemisphere can leave a person impaired in speaking, understanding or reading, without affecting their non-verbal abilities. But how far can different components of language fractionate? Documenting language deficits in people with different patterns of acquired language disorder has significantly advanced our understanding of issues such as how meaning is represented in language (semantics), the way in which speech sounds (phonology) influence verbal short-term memory, the relationship between spoken and written language, and the extent to which there is overlap in receptive and expressive language processes. As we learn more about patterns of language breakdown, we become better able to assess language deficits, sometimes with the intention—and always with the hope—of devising more effective interventions.

In parallel with these developments, there have been major advances in understanding the nature of language representation in children who fail to acquire language in a typical fashion. Our focus here is on children who have no evidence of brain injury, but whose language difficulties appear to have a predominantly genetic origin [1]. It would be naive to take models based on acquired disorders and simply apply them to such children. Brain injury or disease in an adult produces damage to a mature system that has developed specialized subsystems for handling different aspects of language, whereas in the child, factors that disrupt language learning may mean that a mature, differentiated system never develops. These differences between acquired and developmental disorders are important and have led to much debate [2–4]. Nevertheless, despite these

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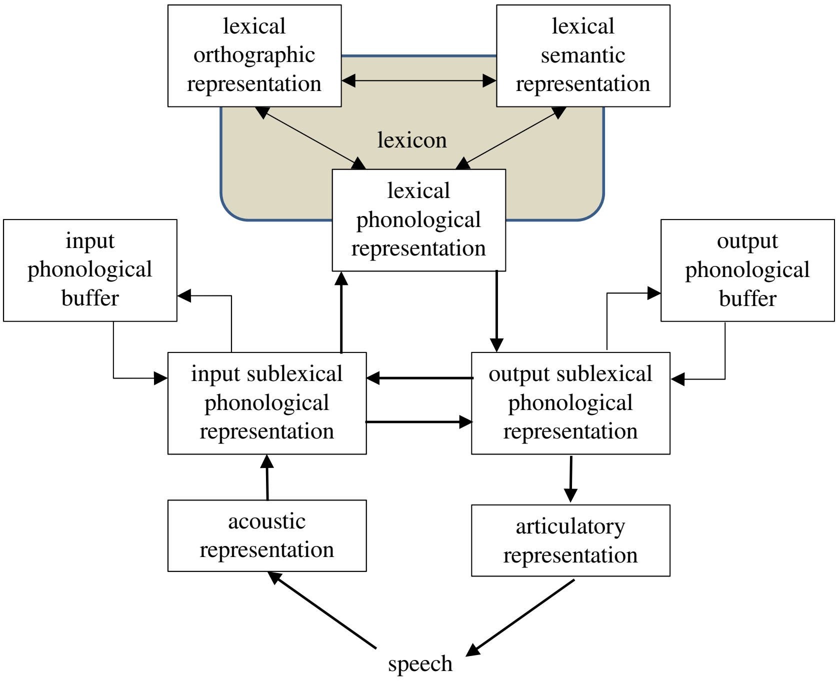

Figure 1. A traditional 'box-and-arrow' model of processes involved in recognizing and repeating spoken words, based on [5]. (Online version in colour.)

differences, many of the questions and issues central to developmental studies overlap considerably with those addressed with acquired, adult disorders.

There have also been parallel changes in the two fields in theoretical approach. For example, as we discuss later, traditional box-and-arrow models that posit separate pathways for rule application and for lexical lookup of spoken or written words are being supplanted by models that involve statistical, probabilistic learning of regularities and exceptions. In both acquired and developmental disorders, an initial emphasis on the nature of impaired representations has expanded to incorporate disorders that arise because of learning deficits or poor access to representations. Models of typical development can provide a bridge between these two domains, by clarifying how the adult system emerges, and identifying ways in which this development can be disrupted.

It is noteworthy, however, that despite these parallel questions and developments, there has been a lack of contact between researchers dealing with acquired disorders and those who study developmental deficits or typical development. While there have been occasional calls for closer integration, in practice these sub-disciplines of neurolinguistics have evolved independently, each pursuing its own models and methods. Our goal in this special issue is to examine the interface between these two domains, with the aim of opening new perspectives on old questions.

2. Some background: traditional approaches to acquired and developmental language disorders

(a) Acquired disorders

One focus of cognitive neuropsychology has been to identify different levels of representation that are involved in language processing. For example, figure 1 shows one version of a 'box-and-arrow' model for specifying the different types of representation that might be required to recognize or repeat a spoken word or nonword. The boxes show the representations, with arrows specifying the processes used in translating between them. According to this model, an input phonological representation of a familiar word will activate the corresponding lexical phonological representation which will then link to the semantic system for word comprehension, and also to the phonological output lexicon, enabling the person to say the word. However, given that we can repeat sound sequences we have never heard before, we also need a route whereby the phonological input can make direct contact with a sequence of (non-lexical) speech commands (output sublexical phonological representation).

Early research in cognitive neuropsychology employed data from patients to specify the different kinds of representations and processes that might be needed to explain both normal and impaired language performance. Patterns of cognitive impairment were then used, perhaps somewhat circularly, to infer that a certain level of representation, or translation between types of representations, was damaged by a brain lesion. For instance, patients with semantic dementia can repeat long, phonologically complex words (such as *stethoscope* or *caterpillar*) without difficulty but are severely impaired when asked to say what the words mean or even to point to a picture of the target word among a set of pictures, all from the same semantic category. By contrast, patients with progressive non-fluent aphasia succeed well at the 'pointing' part of this Repeat-and-Point test [6], but make many errors when attempting to repeat the words. These two patterns of performance can be interpreted, with reference to figure 1, as follows: in semantic dementia, there is damage to the lexical-semantic representations at the top right of the figure, or possibly to the whole lexical 'triangle' at the top; for the non-fluent aphasics, there is damage to one or more of the phonological boxes on the right-hand side involved in speech output. It is also possible that the repetition deficit could reflect a problem with the input phonological buffer; but note that—in this framework—the lexical phonological representations must be functioning to enable comprehension of the spoken word.

Cognitive neuropsychology developed in an era pre-dating the availability of sophisticated brain-imaging techniques. In any case, advocates of 'ultra' cognitive neuropsychology regarded brain-imaging as largely irrelevant to the enterprise of specifying cognitive models. As Coltheart [7, p. 23] put it: 'In order to localise the modules of a cognitive system, we must first know what the system's modules actually are. So we must begin with a model and then seek to do localisation research'. As this quote makes clear, however, the quest was for discovery of subsystems that were modular, and hence potentially independently destructible.

Double dissociations, where two people with brain lesions have opposite patterns of symptoms, were a cornerstone of the cognitive neuropsychology approach, because they were seen as evidence for modularity. For instance, Vallar & Baddeley [8] described a post-stroke patient who had poor verbal short-term memory, with limited ability to repeat even short sequences of familiar words or digits, yet whose understanding of spoken language was largely intact. It could be argued that comprehension is just a less demanding task than repetition, except that we can find the opposite pattern of impairment: for example, patients with semantic dementia typically have forward and backward digit spans within, or indeed sometimes at the high end, of the normal range, yet are severely impaired at comprehending spoken or written language [9]. Such observations led to the conclusion that comprehension is largely independent of short-term memory (though this conclusion depends on how memory is assessed [10]). However, serious challenges have been mounted against such a strong reliance on double dissociations by those noting the circularity of the logic and the lack of falsifiability of modular accounts [11,12]. Furthermore, connectionist modellers have demonstrated that it is possible to produce double dissociations from non-modular systems [13].

(b) Developmental disorders: traditional approaches

Studies of developmental language disorders have taken a wide variety of different approaches, depending on the theoretical background of the researchers. Those coming from the Chomskyan perspective in linguistics tended to see language impairment as reflecting problems in a modular domain-specific system (e.g. [14,15]). This viewpoint had some conceptual similarities with the field of developmental cognitive neuropsychology, which used models derived from the study of adult disorders to account for developmental impairments of language and literacy [16]. Clearly, children know less than adults, but both the Chomskyan approach and the developmental cognitive neuropsychology approach assume that the basic architecture of the cognitive system is the same in children and adults; children learn more words and use more complex grammar as they grow older, but the fundamental nature of phonological, lexical and syntactic representations remains unchanged [4,17].

Researchers from developmental psychology, by contrast, mostly rejected this position, and took instead an empiricist approach which assumed that linguistic representations developed from more general perceptual and motor functions. On this view, domain specificity of representations was something that developed over time, rather than being innately specified [18]. Such an approach led naturally to a search for impairments of perception, action, attention, memory or conceptual knowledge that might be responsible for language impairments [19].

Here, we consider examples of recent research that have modified or refined our understanding of these issues.

3. The changing landscape in acquired and developmental disorders

(a) Probabilistic and dynamic models

Bishop [20] noted that children with language impairment who make errors on verb morphology may nevertheless perform above chance on tasks testing their knowledge of the relevant grammatical rules. This suggests that they must have some relevant grammatical knowledge, but their ability to use it is unstable, perhaps because of difficulty with online computation of relationships between syntactic elements in complex grammatical constructions. An outstanding question is whether problems with computational complexity are confined to the syntactic domain, as argued by Van der Lely [21], or whether they form part of a more general deficit that extends to affect other systems.

In a similar vein, Mirman & Britt [22] describe a range of phenomena in acquired aphasia that are not readily explained in terms of impaired language representations. Some patients appear to have difficulty accessing lexical information, yet their performance on specific items is inconsistent from trial to trial, and/or influenced by factors such as presentation rate or provision of cueing. As these authors note, to account for such phenomena we need more dynamic and probabilistic models of language processing, in which access to a lexical representation may be influenced by levels of activation and inhibition both within and outside the language system.

To develop and evaluate dynamic models, we need methods that allow us to tap processing as people with language impairments comprehend and produce language [23]. Norbury [24] demonstrates the utility of measuring eye movements as people plan and produce language, and Nation [25] discusses the 'visual world' paradigm that tracks eye movements to various objects as a spoken word unfolds. These methods are ideal for use with children as well as patients with aphasia [26] as they require little by the way of overt task, yet provide time-locked data detailing the course of language processing which can then be modelled (e.g. [27]).

Overall, researchers studying both acquired and developmental language disorders are recognizing the need to develop models that can account for the dynamic nature of language impairments, which may vary according to the demands on cognitive processing within both linguistic and non-linguistic domains.

(b) Models grounded in developmental processes

Written language is one area where there has been considerable debate between proponents of traditional information-processing 'box-and-arrow' style models and an alternative approach informed by connectionist modelling. The dual-route reading framework [28] has been highly influential. Early versions of this model were criticized for being largely descriptive; however, later versions have been implemented

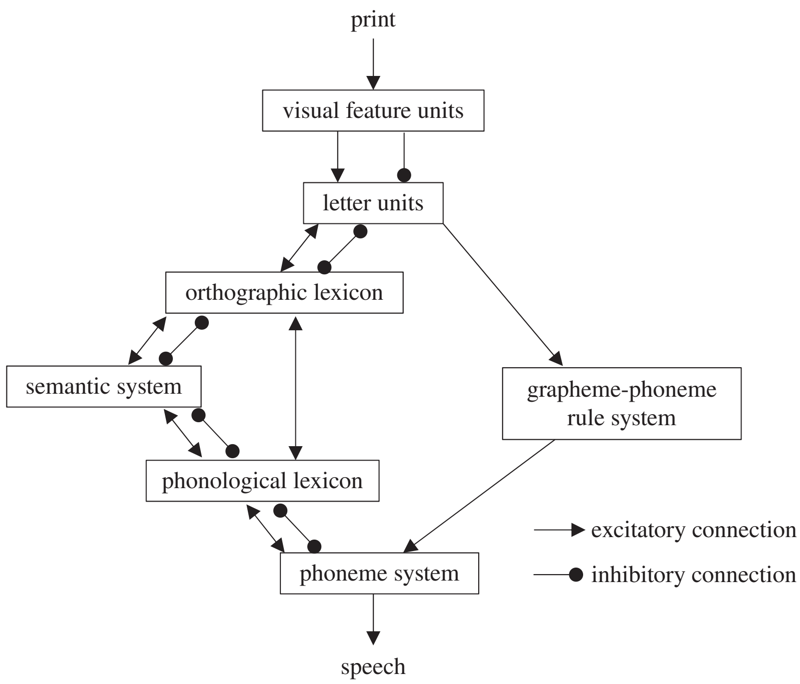

Figure 2. The DRC model, based on [28].

in computer simulations to give a stronger test of their explanatory adequacy and provide further specification of reading subcomponents [28,29]. Such implementation has generated testable hypotheses that have in turn refined the model, but the DRC (dual route cascaded) model remains true to the cognitive architecture of the original box-and-arrow model (figure 2). By contrast, computational models within the parallel distributed processing (PDP) approach [30,31] led to a more radical rethinking of how words are read aloud, and how behaviour can go astray in acquired dyslexia. In these so-called triangle models (figure 3), instead of localist representations that code for individual words or grapheme–phoneme correspondences, knowledge corresponds to activation over sets of distributed representations coding phonology, orthography and semantics—the three corners of the triangle.

The DRC and the triangle models differ from each other in numerous ways. An important difference is that although both approaches include more than one procedure for computing phonology from orthography, in the DRC model these procedures or 'routes' differ fundamentally in their method of operation; by contrast, in the triangle model all routes operate on the same principles, such that the latter has sometimes been labelled a single-mechanism approach. Another critical difference is that the PDP approach employed in the triangle model has learning at its heart, whereas the DRC does not attempt to provide an account of how the system develops.

Perry *et al.* [32] described a Connectionist Dual Process model (CDP+) which takes the best features from the triangle model and the DRC, using connectionist-like sublexical processing in a dual-route architecture, to achieve good prediction of individual item-level reading. Ziegler *et al.* [33] describe how such a model can be extended and adapted to consider how children develop an orthographic lexicon. As a theoretical basis, they use the self-teaching hypothesis, first described by Share [34], which comprises two basic principles. First, letter-sound knowledge and rudimentary decoding skills provide young children with a means of translating a printed word into its spoken form. In turn, this successful (but potentially laborious) decoding experience provides an opportunity

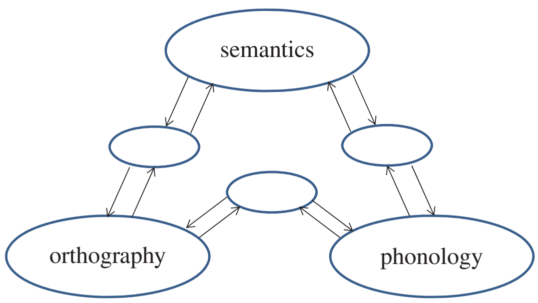

Figure 3. The triangle model, based on [31]. (Online version in colour.)

to acquire word-specific orthographic information of the kind needed to support fast and efficient word recognition. This hypothesis regards phonological decoding as the essential and fundamental basis for reading development. Ziegler *et al.* ask whether implementing a 'learning loop' into the Connectionist Dual-Process model, akin to the self-teaching mechanism described by Share, mirrors the behaviour seen in children as they learn to read. They demonstrate that if the model is given a relatively small set of grapheme–phoneme correspondence rules, it develops word-specific orthographic representations. This captures the central tenet of the self-teaching hypothesis nicely and demonstrates how a computational model of reading designed to account for skilled reading and its breakdown can be adapted to consider development.

Importantly however, theories of reading aloud stemming from the triangle model [30,31] assume that an account of skilled processing (and its breakdown in cases of acquired disorder) needs to be grounded in understanding how the system developed. Woollams [35] discusses the Primary Systems Hypothesis—an account of the language system, allied with PDP computational modelling, that is informed by developmental issues. It sets our ability to read words within a broader context, arguing that as a recent skill in human evolution, reading is likely to depend on more general systems that have evolved to support primary functions such as vision and language. On this view, learning to read is a process in which the specialized functions of reading develop out of these more primary systems; this has much in common with the process that Dehaene [36] has referred to as 'neuronal recycling', and it provides a close link with developmental theories that see reading emerging from oral language skills [37]. Indeed, both the developmental and acquired perspectives share the common theoretical framework provided by the triangle model.

In keeping with the general nature of the Primary Systems Hypothesis, PDP models of verb processing [38,39] and Patterson & Holland [40] suggest that some patterns of acquired impairments in inflectional morphology may be more sensibly attributed to a general phonological impairment than a deficit specific to morphology. They also note that research on such acquired disorders should pay more attention to the research on inflectional morphology in developmental disorders [20]. Westermann & Mareschal [41] focus on a different question—how categorization develops from the interface of a baby's early visual perception with his or her exposure to verbal labelling of objects, but their model shares much in spirit with the Primary Systems view, not least the principle that specialization can develop from general learning mechanisms that extract statistical regularities from perceptual input.

As noted by Mirman & Britt [22, p. 11], computational models are valuable as they provide 'a concrete implementation of a proposed theory that can then be empirically tested to evaluate whether it truly accounts for the observed data and to make novel predictions'. While some developmentalists work within a theoretical framework offered by computational models [37], future work could benefit from a closer coupling of developmental data and computational modelling. The papers by Ziegler *et al*. [33] and Woollams [35] demonstrate the power and utility of this and, although they differ in approach, both share commitment to the principle that understanding development is important.

There are advantages in having a model that can be implemented, rather than one that simply is an abstract representation of theoretical relationships. However, a disadvantage is that such implemented models are inevitably of limited scope. For instance, most language models that actually 'speak' (that is, yield output that can be phonologically realized) are restricted to monosyllabic words [42]; models of sentence processing are limited to simple sentences rather than those involving long-distance dependencies [43]. It is early days in this enterprise, and we have already come a long way in terms of having working models. Scaling models up to cover the full range of linguistic phenomena, however, is immensely challenging, especially when moving away from orthographic and phonological forms to consider semantic and conceptual representation [44]. The danger is that we may end up concentrating too narrowly on those areas of function that can be modelled via relatively simple representations. For instance, the ability to transform an English verb stem such as *blink* or *drink* into its past-tense form (*blinked*, *drank*) has been modelled with some success [45], but the focus has been mainly on how to form correct past tenses for regular and irregular verbs, a limited aspect of morphology even in the rather morphologically impoverished English language. Research on disorders has accordingly emphasized impairments of inflecting regular versus irregular verbs, but both Bishop [20] and Patterson & Holland [40] conclude that tense-marking difficulties in acquired and developmental disorders may arise at a different level of processing, i.e. identification of the semantic and grammatical conditions that dictate when tense-marking is required. We currently lack models that can learn these conditions from naturalistic language samples that include complex syntactic structures.

(c) Complexity and change in phonological representations

Phonological representations are at the heart of models of both reading and language, and are more amenable to modelling than semantic or syntactic components because languages use a restricted repertoire of phonemes. Nevertheless, it is clear that language users make ample use of phonological information beyond the level of individual phonemes [46]. From quite an early age, children are sensitive to higher order aspects of phonological structure, such as complexity of clusters, stress, word position and sequential statistical likelihood (the probability of one phoneme following another). These aspects are often ignored when studying phonological deficits, yet have been shown to influence performance.

Phonology also provides a good example of how representations can develop as children acquire more linguistic knowledge [47,48] and then as they learn to read [49]. Cross-linguistic studies show that phonological structure of the native language largely determines which speech sounds a person can readily produce and perceive. The difficulties experienced by native Japanese speakers in perceiving and producing the /r/–/l/ distinction are well known. English speakers, by contrast, may have great difficulty perceiving length differences that are used to contrast meaning in Finnish vowels. Most speakers of European languages find it extraordinarily hard to distinguish the full complement of phonological tones in a language such as Cantonese, or the different pitch accents of Japanese [50]. Furthermore, phonological representations extend beyond individual segments: for instance, Dupoux *et al.* [51] showed that native speakers of Japanese had difficulty perceiving the difference between /ebzo/ and /ebuzo/. The researchers had predicted this outcome because Japanese does not contain consonant clusters, and intrusive (epenthetic) vowels are often produced by Japanese speakers when attempting to produce such clusters in a second language (e.g. the name of the fast-food chain McDonalds in Japan is pronounced 'ma-ku-do-na-ru-do'). By contrast, native English speakers found it hard to distinguish between /ebuzo/ and /ebuuzo/, where /uu/ denotes a lengthened vowel, whereas Japanese speakers found it easy to detect this contrast, which occurs in their native language. Most current tests of phonological skill, and models of phonological processing, fail to capture these more complex aspects of phonology, focusing instead on perception or production of individual phonemes.

(d) Learning in development and in recovery

By definition, children with developmental language or literacy impairments have a specific learning disability. For many years, this was seen as a consequence of a deficit either in perceptual processing or in underlying language representations, depending on one's theoretical persuasion. More recently, however, there has been interest in the idea that the learning process itself might be impaired [25,52]. Such a view is exemplified in the procedural deficit hypothesis of developmental language impairment [53]. According to this hypothesis, deficits in the fronto-striatal and basal ganglia circuits are considered core and responsible for impairments in

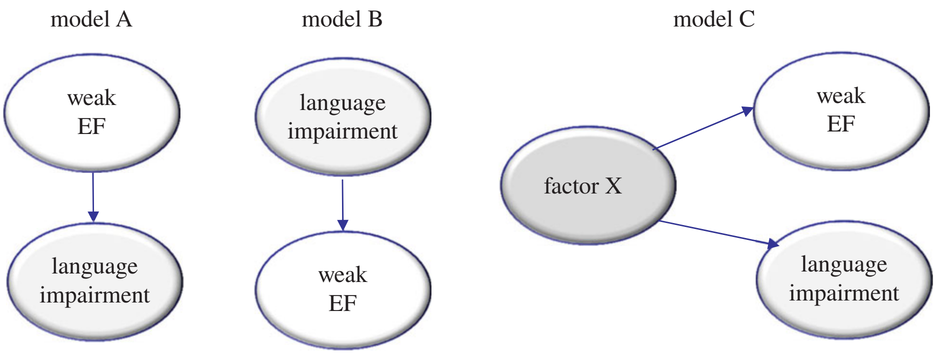

Figure 4. Possible causal models to explain correlation between EF and language deficits. (Online version in colour.)

particular components of language that might be especially dependent on the procedural system, such as syntax and phonology. On this view, there is a specific deficit in procedural learning alongside preserved declarative skills supposed to be more important for acquiring lexical-semantic aspects of language. By contrast, other learning accounts are more general, proposing that individuals with language impairment have difficulty extracting abstract knowledge from statistical regularities in the input (see Nation [25]). Regardless of how learning deficits are best characterized theoretically, however, it is clear that even with extensive training and practice, children with language impairment can be slow to learn, generalize and automatize skills [54].

Much more research is needed to begin to understand the nature of learning deficits in children with developmental disorders of language. Ideas discussed in this special issue suggest at least three ways in which work in this area can benefit from insights gained from different perspectives. One, as discussed by Nation [25], is the growing literature exploring learning and lexical acquisition in adults (e.g. [55,56]). These experiments demonstrate the continuous and dynamic nature of learning and provide a potentially powerful methodology to consider individual differences in learning. The second stems from computational models, which may throw light on mechanisms and consequences of implicit and statistical learning, as discussed by a number of authors. For example, Dell & Chang [43] offer a model of speech production that demonstrates how each encounter with a word provides a learning opportunity. Language experience provides the basis for the language user to make predictions about an upcoming word; this in turn leads to prediction error and to priming, a form of implicit learning which results in changes to the knowledge base that then influences the processing of a word in subsequent encounters. Third, connectionist architectures provide an opportunity to simulate learning in development (e.g. [37,41]). Computational models can be modified to simulate different kinds of learning deficit and also re-learning in adults, for example, post-stroke [57]. This approach opens up the possibility for accounting for variation in different types of disorder: our simulations might predict different patterns of impairment in adults with degenerative disorders of slow onset, compared with those with an abrupt onset.

(e) Executive functions: attention and inhibition

Basic language abilities such as comprehending and producing spoken words are traditionally considered 'encapsulated' modules, which are acquired and used without conscious effort and without awareness of the underlying representations or processes [58]. Executive function (EF), on the other hand, has generally been considered to involve controlled, deliberate operations. Nevertheless, some studies in both acquired and developmental fields have suggested significant relationships between people's skill on executive tasks and their language functioning. Mirman & Britt [22] note that post-stroke performance on certain EF tests correlates with impairments on lexical-semantic tasks such as picture naming, word-to-picture matching and picture–picture matching (see also [59]). In a similar vein, EF deficits have been reported in children with specific language impairment [60,61].

Before considering alternative interpretations of this association, it is worth stressing that EF is not a unitary construct, but encompasses a range of functions, including planning, generativity, inhibition, set-shifting, working memory and attentional control. These are all functions that can be impaired by frontal lobe lesions, but they can be dissociated in adults [62,63]. Some definitions of EF extend to consider traditional IQ measures such as Raven's matrices. Thus, when we consider how EF relates to language impairment, we need to take into account the specific function that is measured, as they are not interchangeable.

Figure 4 shows three possible models that can account for an association between EF and language impairment: (A) EF affects language functioning; (B) language functioning affects EF and (C) a third factor, X, influences both EF and language.

Model A, in fact, can be taken in two ways: the superficial and the deep. At the superficial level, we may designate a task as a language task when in fact it depends heavily on executive skills. In effect, EF may act as a confound. Ramus & Szenkovitz [5], for instance, noted that dyslexia is often characterized in terms of impaired phonological representations. They showed, however, that phonological deficits are seen only in certain tasks, and may be unimpaired when a task does not tax speed or short-term memory or involve conscious judgements. In a similar vein, Protopapas [64] notes that a child may fail the so-called phonological tests for reasons other than poor phonology, such as problems with EFs of attention and inhibition. These authors emphasize the importance of analysing task demands rather than just taking at face value the label given to a language task. In particular, they note that we may find that results differ when an effort is made to minimize the executive and attentional demands of a task.

Mirman & Britt [22] consider the idea of a deep link between EF and language. In this case, EF is not a confound, but is intrinsically involved in language function. They propose that specific aspects of EF are important in semantic control. When a spoken word is heard, several candidate lexical entries will be activated. In order for the correct word to be identified, it is necessary to enhance specific activation of its lexical entry, while inhibiting other entries. Thus, a competent language user needs not only to have access to lexical representations, but also to maintain an appropriate balance of activation and inhibition. This in turn may depend on focusing attention so that top-down knowledge can influence levels of activation. Mirman & Britt suggest that semantic access deficits reflect difficulty with these processes of semantic control, which are seen as engaging the same kind of executive processes that are involved in performing traditional neuropsychological tests of EF. While this is an intriguing perspective, and fits with the idea that inhibition and attention are key features of executive processing, it would imply that the type of conscious, controlled processing involved in a traditional neuropsychological task is sensitive to the same type of inhibitory and attentional skills as are automatically deployed without conscious awareness in rapid processes of lexical selection. This remains to be demonstrated. Developmental cases could provide a particularly sensitive test of this idea, because EF is impaired in both children with language impairments and in those with autism, but with rather different test profiles in the two groups [24,65,66].

The explanation offered by model B is less theoretically interesting, but does not conflict with the traditional view of language as a modular process. This maintains that language skills are deployed when doing executive tasks. For instance, executive tasks may be facilitated by using inner speech to keep track of instructions or talk oneself through a set of operations [66]. Thus, even an ostensibly non-verbal task, such as Raven's matrices, may benefit from having sufficient language skill to reason out the problem verbally, using covert speech.

Model C rejects the notion that there are key dependencies between EF and language processes: rather, they tend to co-occur because they are influenced by the same causal factors. For instance, damage to or delayed development of the frontal lobes may impinge on brain regions important for EF, and on adjacent areas implicated in language processing.

Intervention studies could be informative for distinguishing causal accounts by seeing whether improvement in EF leads to gains in language functioning. There is growing interest in developing EF interventions for use with children [67] and in patients with brain injury [68], so this should be a feasible possibility for future research.

(f) Ways of thinking about causality

Bishop [2] noted a number of problems in the application of cognitive neuropsychology to developmental disorders, one of which concerned causality. She considered the case of a hypothetical child who had a hearing problem early in life (for example, from persistent ear infections) that subsequently resolved. When we come to test the child in middle childhood, we might find evidence of poor language skills, but no auditory deficit. Nevertheless, the cause of the problem might have been an auditory deficit. This example illustrates the importance of, but also the potentials snags in, determining underlying causes.

Much of the discussion of this issue in the literature invokes a distinction between proximal and distal causes. Unfortunately, however, these terms have been used with overlapping but distinct meanings by different researchers. In biology and medicine, a proximal cause is something that is close in time or sequence to the construct it is causing. A distal cause is further back in time or space. However, in the context of understanding language disorders, we have not only the temporal dimension, but also a distinction between levels of description, i.e. etiological (neurobiological, genetic or environmental causes) and cognitive factors. Hulme & Snowling [69] used the example of smoking as a distal cause of lung cancer to make two additional points that are important in helping us understand developmental disorders. First, the terms proximal and distal are relative and as theories are refined and more causal steps are identified, a stated proximal cause may become less proximal. Second, causes are often probabilistic rather than deterministic and they operate alongside other factors that confer risk or resilience, not in isolation. Consideration of the relationship between lung cancer and smoking is helpful here as the pathway from smoking to mutations of cells to the formation of a cancerous tumour is clearly probabilistic, as some people develop lung cancer, despite never having smoked, and other life-time smokers do not develop cancer. Because of the confusion surrounding use of the terms proximal and distal, we prefer to avoid these terms and simply note that causes of any disorder can be multiple and can operate at (and can be described at) genetic, neurobiological, experiential and cognitive levels. Their impact may vary with the stage of development in children, or with the point in a recovery process in acquired disorders. Furthermore, the combined influence of two risk factors may be different from that predicted from either alone [70].

(g) Ways of thinking about heterogeneity

Research into both acquired and developmental disorders of language has to deal with the sources and the consequences of heterogeneity, as illustrated by most of the papers in this issue. In acquired research inspired by the cognitive neuropsychological tradition, heterogeneity in the patterns of disorder is seen as a natural consequence of a complex system comprising processing components that may be differentially spared or impaired. Heterogeneity in the symptomatology of a developmental disorder might be associated with variables such as age (e.g. the manifestations of language impairment might be different in a 6-year-old versus a 12- or 20-year old) or the presence of a comorbid disorder such as attention deficit hyperactivity disorder. Typically, then, the approach to understanding the causes of heterogeneity has been different in the two traditions. But might the approach of one tradition have anything to offer the other? Can a detailed analysis of the componential nature of the adult language system help us understand developmental disorders? And in return, can we better understand acquired deficits, and the cognitive models that underpin cognitive neuropsychology, by considering how language develops?

Castles *et al.* [4] offer a discussion relevant to these questions in the context of reading. There is now considerable support for the view that a phonological deficit is a major contributing factor in developmental dyslexia [37]. The evidence base for this is impressive in volume and range, with group comparisons, longitudinal studies and intervention studies providing complementary data; yet questions remain, for example, concerning the precise nature and origins of the phonological deficit [64] and how it interacts with other factors to predict outcome [71]. Also, as noted above, the strength of this relationship may depend on the phonological task employed [5].

An area of discussion in the literature is whether a strong phonological deficit hypothesis can accommodate heterogeneity in reading profile in children with dyslexia. For sure, reading is a complex skill, even when we restrict the domain to reading aloud of single words. Could at least part of the heterogeneity we see in a population of children with reading difficulty indicate different types of developmental dyslexia, characterized by cognitive deficits in different components of the reading process, and potentially associated with different causes? A cognitive neuropsychological approach involving detailed assessments of individual children, with reference to a cognitive model of the processes involved in reading words, might seem an ideal way to tackle this question. Using this approach, Castles & Coltheart [72] reported developmental cases reminiscent of patients with acquired surface dyslexia (poor irregular word reading, satisfactory nonword reading) or phonological dyslexia (poor nonword reading, satisfactory irregular word reading). This, alongside other evidence, is certainly consistent with heterogeneity in the manifestation of dyslexia; but there has been debate over whether this reflects qualitatively different subtypes. Castles *et al.* [4] clarify that they are not claiming that surface and phonological dyslexics are qualitatively unusual: rather they occur at a frequency in the population that would be expected, given what we know about the correlation between nonword reading and exception word reading. This view is compatible with the balance of evidence that shows the two subgroups falling on a continuum, with the majority of children showing a mixed picture [73–75].

As mentioned above and discussed further by Woollams [35], the triangle model of reading aloud entails a division of labour between two pathways, a direct pathway (connecting orthography to phonology) and a semantically mediated pathway. Plaut *et al.* [30] demonstrated that the direct pathway alone could learn to read aloud correctly all of the words on which it was trained, including those with an atypical mapping between spelling and pronunciation (e.g. *pint* or *sew*) and those with atypical orthographic patterns (e.g. *yacht*); at the same time, this single pathway could generalize fairly well to novel patterns as reflected by nonword reading. However, the model performed more successfully, and could account for a larger range of data including evidence from acquired disorders of reading, if it used a mixture of the two pathways. The division of labour between the direct and semantic pathways can vary as a function of development and reading experience and this has been modelled, e.g. by training a model with degraded phonological representations or with reduced input from semantics to phonology [30]. Typically-developing children appear to vary in their division of labour [76,77], raising the interesting possibility that profiles of acquired reading disorders in adults following brain injury might relate to their premorbid division of labour. For example, although there is a close association between semantic dementia and surface dyslexia, there is variability across individual patients in the stage of semantic decline at which surface dyslexia emerges [78]—a plausible consequence of premorbid individual differences in the degree to which the developing reader learned to rely on the two pathways.

4. The clinical interface: some key questions

A major aim is to develop theoretical knowledge to a point where it can be used in intervention, but there is often a disconnect between theoretical and applied work. People with language impairments cannot wait until we have perfect understanding of how the brain processes language: they need help now. In any case, not all clinicians are convinced that the guidance offered by cognitive models is helpful in deciding how to treat a disorder [79]. The usual approach when trying to apply model-based therapy is to identify and intervene at the point in the process where difficulty arises, but this is not always possible. For instance, there would be no point in trying to teach a child to decode speech if there was a profound hearing loss caused by damage to the cochlea; instead, one would need to think of ways around the problem—e.g. learning sign language or lip-reading, and/or providing a cochlear implant. Even where the basis for an impairment is not so clearcut, some types of problem are easier to remediate than others. A key question for anyone working on intervention is to know when to try to tackle a person's area of weakness, and when instead to attempt to compensate for the problem by bypassing it.

Some aspects of language and literacy problems appear easier to remediate than others. In the domain of literacy, Hulme & Snowling [37] note that it is possible to train letter knowledge and phonological awareness and demonstrate associated benefits on word reading accuracy, but attempts to train rapid naming—another correlate of reading—have not been successful [80] and reading fluency often remains a problem for poor readers even after reading accuracy has improved [81].

A systematic review of speech and language therapy for primary language impairment concluded that a range of methods appeared effective for improving children's expressive phonological problems and weak vocabulary; but there was only mixed evidence for an impact on expressive syntax, and no indication of effective interventions for receptive language [82]. Subsequent work has suggested that it is possible to improve children's understanding of specific grammatical constructions with explicit metalinguistic training [83]. Nevertheless, it seems very difficult for some children to acquire rapid and automatic understanding of different meanings conveyed by word order, even though their performance in explicit choice tasks is well above chance level [54]. This result was obtained despite use of a method that embodied optimal features for an intervention study: the intervention was embedded in an attractive computer game; an errorless-learning method was adopted, whereby children could use cues to see the correct response if need be, and were allowed to continue trying until they got the correct answer; and they were active participants in the game, having to drag-and-drop computer images to appropriate positions on the screen in order to obtain rewards. With this method, it was possible to provide numerous training trials with given grammatical structures; but the amount of improvement was no greater than for other children given no additional intervention.

For acquired language and literacy disorders, less is known about which types of problem respond best to intervention. For adults, the outcome may depend upon characteristics such as the lesion location or age of the patient as well as on the particular deficit [84]. Unsurprisingly, perhaps, treatment for non-progressive language disorders consequent on stroke is more likely to be beneficial than for the progressive aphasias that can occur in neurodegenerative diseases [57,85].

An important point noted by Wilson & Patterson [79] is that models of learning and re-learning are still in their infancy. In this regard, we need more information on basic questions such as when and how often treatment is best applied, and how generalization from treated to untreated material can be enhanced. It may turn out that treatment features such as spacing of training [86] and opportunities for consolidation during sleep [87] could be as important as the specific materials used in intervention. An exciting recent development concerns the use of brain stimulation techniques—transcranial magnetic stimulation or transcranial direct current stimulation—as adjuncts to enhance language therapy [88,89].

5. Future directions: acquired and developmental disorders

The overview we have provided here identifies several issues where greater interaction between those working on developmental and acquired disorders could be fruitful. First, we now have several implemented models for processing of written and spoken language that have been applied to acquired disorders [22,35,42–44]. Some of these model the learning process as well as the stable state, yet applications to developmental disorders are rare (but see Ziegler *et al*. [33]). The advantage of computational models is that they yield clear predictions which can be tested against real data. Furthermore, they have the potential to generate information about factors that might improve learning or re-learning, factors that could be key in devising more effective interventions.

A second issue concerns a growing interest in inter-relationships between different cognitive systems. The primary systems hypothesis has been applied to acquired disorders, yet much of its motivation comes from developmental considerations. For those working with children, there has long been interest in the idea that there may be interactions between different cognitive systems, but the evidence for this varies considerably across domains. Thus, there is growing acceptance of the idea that oral language skills are key for reading development: not only do oral language difficulties predict reading impairment, but intervention that improves vocabulary can benefit reading comprehension [90]. However, the evidence for an impact of lower level perceptual deficits on language and reading development is far from clear. Mostly, this has been investigated with studies of auditory processing, which appears less important than was originally thought [91]. The evidence for visual perceptual deficits as a cause of developmental dyslexia is conflicting [92,93]. However, the kinds of perceptual task that have been used are different from those investigated in cases of acquired reading disorder, and it would be of considerable interest to see whether, for instance, dyslexics do poorly on sensitive tests of face perception—or whether children who are identified as having poor face perception skills are at risk of reading problems. This possibility is raised by recent research assessing adults with lesions to either left or right ventral occipito-temporal cortex [94]. According to strictly modular views of domain-specific visual object processing, these two brain regions are thought to be specialized for written words (on the left) and faces (on the right). Although the patients in this study did indeed have the substantial deficits predicted by side of lesion, each case series also revealed milder deficits in the other domain. That is, the patients with lesions involving the visual word-form area on the left were profoundly alexic but also mildly prosopagnosic, and those with lesions affecting the fusiform face area on the right were severely prosopagnosic but also mildly reading-impaired.

Finally, we have noted the importance of developing models that can simulate processes of learning and re-learning. An elementary fact taught to most psychologists is that if you repeat something often enough it will be learned, yet it is clear that there are enormous variations in learning that are influenced both by individual differences between people and what they already know, and by the nature of the material to be learned. The challenge for the next decade is to come to grips with the causes of such variation. If we can do so, we will not only advance our understanding of language processing, but we may also begin to bridge the divide between theory and application.

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