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Lexical learning and lexical processing in children with developmental language impairments

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Lexical skills are a crucial component of language comprehension and production. This paper reviews evidence for lexical-level deficits in children and young people with developmental language impairment (LI). Across a range of tasks, LI is associated with reduced vocabulary knowledge in terms of both breadth and depth and difficulty with learning and retaining new words; evidence is emerging from on-line tasks to suggest that low levels of language skill are associated with differences in lexical competition in spoken word recognition. The role of lexical deficits in understanding the nature of LI is also discussed.

1. Introduction

Words are the building blocks of language. They provide a link between a phonological (or orthographic) form and a referent, resulting in a unit of meaning that can be understood and shared between people. Word knowledge develops early in infancy and before long, children are able to produce and comprehend many thousands of words, using their vocabulary knowledge flexibly and creatively to communicate with others. Words are a crucial component of comprehension, and therefore it is not surprising to find that children who struggle with language during development often have difficulty dealing with words. This is seen most obviously when a child has an impoverished vocabulary: not knowing the meaning of a particular word has clear and detrimental implications for comprehending language which contains that word. For words to drive comprehension however, we need to consider more than whether knowledge of a particular word is there or not. Words and the contexts in which they appear have a close interdependency. A word contributes to the meaning of a sentence but at the same time, the meaning of the word is in part a product of the sentence and context in which it appears. On this view, the possession of vocabulary knowledge for a word is not an all or nothing factor, governed by whether or not a child knows something akin to the dictionary definition of a word. Also important is the ability to retrieve word identities to provide the meaning the listener needs in a given context and to do this rapidly, as the incoming speech stream unfolds in real time.

Word-level deficits are associated with a variety of developmental disorders, most notably developmental language impairment (LI).[1] Before discussing this, it is appropriate to start with a definition of some terms. I use the word *lexical* in a variety of contexts in this review, including for example lexical knowledge, lexical processing, lexical learning and lexical deficits. At a general level, these terms are associated with word-level aspects of language (with a *word* comprising something with a mental representation or concept that is associated with a particular form), as opposed to syntactic, grammatical or discourse-level aspects of language. It is harder to specify more precise definitions, not least because terms are used in different ways in the literature. For example, lexical learning might be assessed by asking children to learn a phonological form and associate it with an object that has a novel but meaningless shape. This taps learning the links between a form and its referent, but the demands on the semantic system are quite low, given the object has little meaning. Or, children might be asked to learn semantic attributes associated with a new object or novel phonological form; arguably, this is different to whatever processes are being tapped when children are learning an association between a form and a meaningless referent, quantitatively and in terms of difficulty, if not qualitatively too. How we measure performance is also a complicating factor. Standard laboratory tasks (such as picture naming, word-to-picture matching, providing a definition, word associations or recall of semantic attributes) might claim to measure whether children can identify, recognize or understand words, but in reality, these tasks are not process pure. Putting to one side non-linguistic factors that influence performance such as memory or executive control processes, language is dynamic and interactive—it is not the case that processing can be neatly portioned into components that can be labelled as identification, recognition and understanding.

From this short overview, it is clear that defining and measuring lexical processes is complex. I take a broad perspective here, consistent with the view that lexical skills are multi-faceted, comprising everything a child knows about a word and its usage. The most obvious index of a child's lexical skill is vocabulary knowledge. Put simply, how many words do they know? Accordingly, this review begins by considering this as I review evidence of vocabulary deficits in children with LI. I then consider the nature of lexical learning in children with LI, before turning attention to whether children with LI differ from their peers as they activate, use and process lexical information.

2. Vocabulary knowledge in language impairment

Vocabulary deficits are common but not universal in children with LI. Generally, children who go on to receive a diagnosis of LI are often 'late talkers', indicative of differences in word learning and knowledge from early in development [5]; there is also evidence that vocabulary deficits maintain in later childhood [6,7]. Although it is widely accepted that children with LI have difficulties understanding words, less clear is how such deficits should be conceptualized, both in terms of their underlying nature, and of their consequences for language comprehension.

A straightforward starting point might be to index the number of words a child knows. Immediately however, we are then faced with the question of what constitutes 'adequate' word knowledge and how this is best measured. Vocabulary size is typically estimated using receptive tasks which require children to choose a target referent from an array of pictures. Arguably however, such tasks are not very sensitive [8], leading McGregor *et al.* [9] to use data from a definitions task to chart vocabulary size longitudinally in 177 children with LI between 2nd and 10th grade (although it should be noted that definitions tasks are not 'process pure' as they place demands on expressive skills and executive function as well as tapping word knowledge). Children with LI were able to define fewer words than control children at each time point, with the magnitude of the deficit remaining stable over time. The availability of data from the definitions task also allowed McGregor *et al.* to make a useful distinction between vocabulary breadth—as described above—and vocabulary depth, referring to how well the children knew the words as estimated from the quality of the definitions they produced. Alongside limitations in vocabulary breadth, children with LI showed reduced depth of knowledge, relative to their peers, and this also maintained over time.

McGregor *et al.*'s finding of deficits in depth as well as breadth is important as it suggests that something about the *quality* of word knowledge is different in children with LI, not just the quantity of words known. This fits with other observations in the literature. Marinellie & Johnson [10] also reported deficits in the quality of definitions produced by children with LI, both in terms of semantic content and syntactic form; they are also less able to use context to cue multiple meanings of ambiguous words [11]. Children with LI produce fewer semantic associates than their peers, producing instead phonological associates, reminiscent of much younger typically developing children [12]. Even after extensive training designed to enhance semantic knowledge of newly learned words, children with LI were less likely to recall semantic associates of those words (N. Munro 2007, unpublished doctoral dissertation, cited in [12]). Taken together, Sheng & McGregor [12] argued that these findings suggest that children with LI show differences in lexical-semantic knowledge and organization. On this view, LI is characterized not only by fragile knowledge of the core meaning of individual words, but fragile semantic connections between words. Potentially, this will have serious implications for comprehension and language use when lexical processing needs to be nuanced, context sensitive and flexible. I return to discuss this in more detail later in this paper.

3. Lexical learning in language impairment

Given these differences in word knowledge when children with LI are tested at a particular point in time, it is not surprising to see differences in lexical learning in laboratory experiments. Children with LI show poor word learning, both incidentally and over more extended periods of explicit instruction [13–21]. These studies point to difficulties learning new phonological forms, but also with learning semantic attributes such as colour, pattern and animacy. A meta-analysis of word learning in children with LI [22] revealed that lexical learning was impaired relative to age-matched peers, but equivalent to younger children matched for language level (some studies matched using a measure of receptive vocabulary, whereas others used mean length of utterance). Learning was modulated by severity, with children with lower levels of language showing worse levels of learning, and by non-verbal ability. Language group differences were larger when experiments contained more exposure trials (suggesting that controls benefit more from repeated exposure than children with LI), and when learning was assessed via comprehension rather than production.

Lexical learning impairments have traditionally been considered as downstream consequences of impairments in other aspects of language or cognitive skill, with a variety of causal hypotheses being suggested. For example, primary grammatical deficits might impede vocabulary growth as children with LI are less able to use syntactic structure to aid word learning (the so-called syntactic bootstrapping, [23]; see [24–26]). Alternatively, lexical learning deficits might be a consequence of either linguistic or non-linguistic processing limitations, with differences in children's capacity to process, store and retrieve information about new words influencing the ease with which new form-meaning associations are made [27–29]. Importantly, however, there is evidence for the causal nature of the relationship operating in the opposite direction—that is, vocabulary knowledge itself contributing to phonological short-term memory ([30] and see [31] for a computational model that addresses causal relationship between phonological short-term memory and vocabulary learning).

A rather different perspective on the nature of lexical learning deficits comes from the procedural deficit hypothesis (PDH; [32]). This proposes that language learning is supported by two memory systems, declarative and procedural. Declarative memory comprises the mental lexicon—a store of memorized word-specific knowledge—and is thus associated with vocabulary acquisition and semantic knowledge. By contrast, procedural memory is akin to the mental grammar and deals with syntax and phonology—computational aspects of language that in this approach are considered to be rule-based. According to the PDH, LI is associated with deficits in procedural memory but an intact declarative system. On this view, vocabulary is seen as a relative strength in LI as it is primarily supported by the declarative system. At the same time, however, the hypothesis recognizes that some degree of vocabulary deficit is often observed in LI, but states that this is a consequence of procedural deficits. Here, procedural deficits would impede lexical learning, with the learning and retention of phonological sequences being particularly vulnerable. Consistent with this idea, children with LI show deficits in procedural learning in both linguistic and non-linguistic domains [33,34] and these might be directly related to grammatical skills [35]. Less clear is whether the declarative system is intact as Lum *et al*. [33] also reported impaired declarative learning for verbal materials, as well as impaired procedural learning.

The PDH discusses one type of implicit learning, procedural learning. Another form of implicit learning has been described in the statistical learning literature and this also provides an alternative perspective on lexical learning in LI. In statistical learning tasks, learners are exposed to a stream of elements that contain regularities, for example, one syllable reliably predicting the occurrence of another syllable. Even young infants are adept at tracking such statistical regularities (e.g. [36]) and at using this knowledge implicitly in ways that are relevant to language, for example, identifying word boundaries in continuous speech. Moreover, infants are able map the outputs of statistical learning (e.g. potential word forms) to referents and to lexical categories, without explicit instruction or reinforcement [37–39], consistent with statistical learning having a role to play in natural language development (for a review, see [40]). Building on this work examining statistical learning and language learning in typical development, Evans *et al*. [41] asked whether children with LI showed differences in statistical learning, relative to age-matched controls. Children engaged in a drawing task while passively listening to 21 min of continuous speech comprising a novel language. Embedded in the speech were ‘words’, identifiable as such by virtue of having high transitional probability (i.e. the probability that one syllable would follow another, thus providing a cue as to where word boundaries could be placed in the speech stream). At test, children were played ‘words’ and ‘nonwords’ and made a judgement as to which sounded most like the sounds they heard while drawing. The LI children were worse than the controls, and their performance was not different to chance levels. In a second experiment, doubling the amount of exposure improved learning in the LI group, who now showed performance significantly better than chance. Interestingly, the children with LI were also poor at detecting statistical regularities in a non-linguistic condition comprising tones.

Much more work is needed to clarify when and why children with LI perform less well on statistical learning tasks. An exciting prospect for future research will be to extend the investigation of statistical learning in LI from the identification of word boundaries to the mapping of form to meaning. Recent developments in psycholinguistics have shown that learning to map words to meaning is a statistical learning process [42–45]. This approach has the potential to help us understand more about the nature and origins of individual differences in lexical learning. We also need to consider the similarities and differences between implicit learning, as embodied in the statistical learning literature and procedural learning. If word learning is the product of statistical learning mechanisms [42], it is more appropriately seen as part of the procedural system, rather than the declarative system. Discussion of the similarities and differences between the PDH and implicit or statistical learning is beyond the scope of this paper but can be found elsewhere [46,47].

Regardless of how we characterize the causes of lexical learning differences in LI, what is clear is that children with LI are poor at learning new words and this might lead to meaning being represented in long-term memory in an impoverished way, lacking in elaboration and connectivity between items and therefore resulting in vocabulary knowledge that is deficient in quality as well as quantity. As noted earlier, this has serious implications for comprehension which both depends on and stems from the activation of appropriate aspects of word meaning, given a particular context and nuance. To examine this possibility directly and in more detail however, we need to move to studies that measure lexical knowledge in a very different way.

4. Lexical processing in language impairment

As noted earlier there is a close interdependency between words and the contexts in which they appear, with words contributing to the meaning of the sentence while at the same time gaining some of their own meaning from the sentence context. Clearly, methods that tap word knowledge in isolation are not sufficient to capture this complex interplay. An alternative way to conceptualize a child’s word knowledge is to measure how they use and respond to words during the course of language processing. A large body of work in psycholinguistics has taught us a great deal about how listeners access and recognize spoken words, and we know a number of features that characterize this in adults (for reviews, see [48,49]). McMurray *et al*. [50] summarize key features as follows: (i) words are activated *immediately* upon receipt of the smallest amount of perceptual input, (ii) activation is updated *incrementally* as the input unfolds, (iii) activation is *graded*, (iv) multiple words are activated in *parallel*, and (v) these words actively *compete* during recognition. While there is more to understanding the meaning of words than how spoken words are initially activated and recognized (see [51,52] in this volume for discussion of semantics and conceptual knowledge), the properties of lexical access and spoken word recognition identified in studies of adults provides a framework to help us think about aspects of word knowledge in children with LI, and indeed in typical development [53,54]. Put simply, do children with LI show any qualitative or quantitative differences in any of these core features of word recognition?

A method that has been used productively to explore the key features of word activation and recognition in adults is the visual world paradigm [55,56]. Here, eye movements are measured as participants view a visual scene (which might comprise an array of real objects or objects presented on a computer screen). At the same time, they are listening to spoken stimuli that describe aspects of the visual scene. As people tend to look at objects that serve as potential referents for the linguistic expressions they hear, monitoring eye movements can tap language processing, as it unfolds in real time. This method holds considerable promise for exploring language processing in children, especially those with developmental disorders [57], as it requires no secondary task or complex instructions, or verbal output. Instead, eye movements are monitored unobtrusively as children hear speech, allowing a relatively implicit measure of processing as it happens.

Although few in number, studies using the visual world paradigm to explore language processing in children with LI have offered some important insights. McMurray *et al*. [50] monitored the eye movements of adolescents with LI to a set of visual scenes, each containing four objects: a target (e.g. *candle*), a cohort competitor (e.g. *candy*), a rhyme competitor (e.g. *handle*) and an unrelated item (e.g. *button*). We know that adult listeners show a systematic pattern of eye movements towards the objects, as the speech stream containing the target word unfolds in time [56]: about 200 ms after the onset of the target word in speech, equivalent looks are seen to the target and cohort competitor, and both are fixated more than either the rhyme and unrelated distractors. As the speech stream continues and the ambiguity between target and cohort is resolved, looks to the cohort competitor decrease, accompanied by a small increase in looks to the rhyme competitor. These findings demonstrate the fine temporal properties of the paradigm, and its ability to chart key features of word recognition such as immediacy, gradation and competition. With these findings as a backdrop, McMurray *et al*. [50] explored the eye movement record of adolescents with LI and asked if, when and how it differs from that of control children. Initial activation was normal, but later in the time course, reduced language ability was associated with fewer looks to the target and more looks to the cohort and rhyme competitors. They used TRACE [58] to model the data and test out a number of hypotheses as to the possible cause of this atypical pattern of eye movements. The best fit to the data came from modelling variation in lexical-level factors, rather than perceptual or phonological factors. Specifically, increasing lexical decay in the model best captured the data, leading McMurray *et al*. to suggest that high levels of lexical decay prevent the target word from being fully active, thus allowing competitors to become more active than they ought to be.

These findings point to differences in word recognition in children with LI that have a lexical locus and a relatively late time course in processing. Additional support for this comes from an experiment reported by Munson *et al*. [59]. This experiment was designed to measure sensitivity to small acoustic differences during the course of spoken word recognition. Previous work with adults [60] revealed that listeners are sensitive to small variations in voice-onset time (VOT) within a phonemic category (i.e. different tokens of /b/, some of which are closer in VOT to a /p/) and that this is revealed in their eye movements as they look at a scene containing pictures of a *beach* and a *peach*, among other items. Specifically, more looks are made to the competitor picture (e.g. *peach*) as the acoustic signal becomes closer to a /p/, even though listeners still categorize the token as a /b/. Consistent with an increase in lexical decay, Munson *et al*. found that adolescents with LI were more likely to fixate competitors than control children, and this showed a linear relationship with the magnitude of the LI. Importantly, however, the language impaired group showed equivalent sensitivity to fine-grained variation in VOT, suggesting no deficits in perceptual or phonological processing. Taken together, the findings of McMurray *et al*. [50] and Munson *et al*. [59] point to children with LI showing increased levels of lexical uncertainty. This does not seem to be a consequence of differences in initial activation but instead seems to reflect later components of processing associated with selecting between competitors.

So far, I have discussed studies that explore the processing of words (and competitors) in isolation. In natural language however, words are usually encountered in sentential contexts. Recent studies using the visual world paradigm with adults have explored how the cohort effect manifests when words are processed in contexts that serve to constrain meaning. Building on earlier work in adults [61], Brock & Nation [62] monitored eye movements as adults heard a target word (e.g. *button*) in neutral versus constraining context (*Joe chose the button* versus *Joe fastened the button*) while viewing a visual scene that contained three distractor pictures and a competitor picture, in this example, some *butter*. As expected in the neutral condition, listeners looked preferentially to the cohort competitor after the acoustic onset of *button*. This effect was significantly reduced in the constraining condition, where the verb *fastened* made the competitor an unlikely referent. The availability of contextual information had a near immediate effect on word identification, operating with a similar time course to the cohort effect itself.

Relevant to our discussion of LI, Brock *et al*. [63] explored this context-on-cohort effect in children with autism, using the visual world paradigm. They found no effect of autism diagnosis: children with autism, like the control children, showed exactly the same effect seen in adults, with context serving to block the cohort competitor effect. Importantly however, children with low levels of oral language (including some children with a diagnosis of LI, with or without autism) showed reduced sensitivity to context: when listening to *Joe fastened the button*, they spent longer looking at the contextually inappropriate competitor (*butter*) than children with better language skills, consistent with McMurray and colleagues' findings of increased looks to competitors in adolescents with LI.

Although not yet tested in children with LI, Huang & Snedeker [54] present data from typically developing 5-year-old children that also point to competition effects lasting longer when language skills are relatively weak. Using the visual world paradigm, adults and children viewed scenes containing a target picture (e.g. *logs*), a competitor (e.g. *key*) and two unrelated distractors while listening to a neutral sentence that contained the target word (e.g. *pick up the logs*). The rationale here is that *logs* should active the (non-present) phonological competitor *locks*, leading *key* to be activated, via its semantic association with lock. If listeners are sensitive to this, they should look more to the *key* than either of the distractor pictures. This is exactly what Huang and Snedeker found, both for adults and 5-year-old children, replicating earlier reported effects with adults [64]. In addition, competition lasted longer for the children, and they occasionally made errors that involved them selecting the competitor rather than the target—an error not made by adults. These data show that children, like adults, show incremental activation across multiple levels of representation, with partial speech input activating candidate lexical items in terms of form and meaning. Importantly however, children are less adept than adults at using subsequent phonological information to rapidly suppress or rule out the phonological-semantic competitor.

To summarize these four visual world paradigm studies: all show that participants with low levels of language (adolescents with LI in [50,59]; older children with LI, with or without autism in [63]; typically developing 5-year-old children in [54]) show competition effects, consistent with the general core properties of lexical access and spoken word recognition outlined earlier. In all four studies, however, competition effects lurked for longer in individuals with lower levels of language skill. It is worth noting that competition-like differences in children with LI have been described in studies using other methodologies such as semantic priming and lexical ambiguity resolution [65–67], gating [68], word spotting [69,70] and delayed repetition [71,72]. Taken together, these observations provide converging evidence and reassurance that prolonged competitor activity is unlikely to be an artefact of the visual world paradigm.

What might these findings mean for sentence comprehension? As semantic analysis begins very early in processing, before word recognition is complete, one can speculate as to how variation in lexical processing (for example, slowness in settling on a single candidate) might have direct consequences for higher level aspects of sentence comprehension. And, if multiple candidate words remain activated simultaneously, the system might get overloaded or bottlenecked, leading to difficulties in syntactic parsing and semantic interpretation. These are underspecified speculations and direct evidence is lacking, but nevertheless, the general notion that inefficiency or uncertainty at the lexical level serves to impede comprehension makes sense. Clearly however, and as noted earlier, studies examining lexical access and spoken word recognition explore the initial inroads into comprehension. Much more work is needed to uncover how the lexical–phonological interactions seen in these visual world studies contribute to (and are influenced by) sentence and discourse comprehension.

5. Linking lexical learning and lexical processing

Learning and processing are generally considered separately in the literature. In reality, however, the two must be intertwined: a processing episode with a word will be influenced by an individual's previous experiences with that word; in turn, the episode will provide a new encounter to add to the accumulated knowledge the individual has of that word, and so influence future processing. Differences in vocabulary size early in development matter as this will influence the statistical properties that are extracted from the input (see [73] for evidence) and in turn, this will serve to influence subsequent learning and processing.

Experiments with adults show that newly learned words soon integrate with existing knowledge and begin to compete with similar sounding words in online processing [74]. Henderson *et al*. [53] recently extended these findings to 7–8-year-old children. Here, children experienced new words that were competitors for existing words (e.g. *biscal* for the base word *biscuit*). Following a period of consolidation, online processing of *biscuit* was slowed, indicating that *biscal* had become sufficiently integrated so as to induce lexical competition. Interestingly, children showed larger lexical competition than adults, reminiscent of the increased competition effects seen in people with LI in experiments using the visual world paradigm. Also, as reviewed earlier, children with LI also show difficulties with consolidating vocabulary [21,22] in laboratory learning tasks. Extending experiments that unite learning and processing, like Henderson *et al*. [53] to children with LI offers rich potential for revealing a great deal more about how differences in learning are related to differences in online processing. This is nicely illustrated in a recent study by McGregor *et al*. [75]. Adults with LI were asked to learn new phonological forms and map them to novel meanings. In addition to measuring encoding skills relative to a typically developing group of adults, learning was assessed following a period of consolidation. The LI adults were poor at learning both form and meaning, encoding less information than control participants; interestingly however, they retained knowledge about meaning over time, but their ability to recall new forms declined over time. Both encoding and remembering were associated with the severity of LI, with those with the most severe deficits in language showing poorer levels of learning. This experiment shows the utility of separating different aspects of learning (encoding versus remembering; form versus meaning) and probing learning over time. Future work could build on this empirical approach and make links with the literature on learning [36–45].

Another way to consider the complex interplay between learning and processing is via computational modelling. This is nicely illustrated by McMurray *et al*.'s [42] dynamic associative model of word learning. Both learning and processing are implemented in the model: learning is accomplished by changing connection weights between words and objects whereas processing is activation in real-time across those weights. In associative accounts, we often think of the need to learn stimulus–response mappings from explicit encounters with words and their referents. The enormity of word learning is traditionally seen as a problem for such accounts. However, if we consider that each learning encounter not only strengthens the mapping between a word and its referent, but also suppresses or reduces irrelevant mappings to all other referents, we see that much more can be learned during each encounter. This process is slow, but McMurray *et al*. make a persuasive case that word learning *is* slow. For children with LI, this process will be slower still. The observation that the model's ability to suppress or 'prune' unnecessary or incorrect associations was an important determiner of learning (which in turn impacted on real-time processing) might have relevance to LI. Simulations showed that the pruning of unnecessary connections drove the system both to learn new words, and to recognize them faster. During processing, unnecessary connections caused auditory input to activate multiple lexical units, which then competed. For children with LI, reduced vocabulary size might be associated with more spurious associations, which would then lead to more competition during processing, and a reduction to the learning power of that encounter. This is speculative, but could be tested by combining modelling efforts with online data from children at different points in development, and with LI.

6. Lexical differences in language impairment: cause or consequence?

Issues of causality are complex. To help frame this discussion, it is helpful to consider two distinctions: proximal versus distal causes and domain-specific versus domain-general explanations. A proximal cause is situated close to the observed behaviour—something awry that directly contributes to the disordered behaviour. We can, for example, posit a cognitive model of spoken word recognition that has a particular component and if children with LI show impairments in this component, this would be an adequate proximal cause of differences in spoken word recognition. Taking a more distal view allows us to ask *why* it is children come to be impaired at processing that component, with a distal cause being the ultimate or underlying cause of the disorder. A domain-specific explanation would be specific to the language system, whereas a domain-general explanation would look beyond language and ask whether deficits in other domains are responsible for the language deficit.

One can certainly make a plausible case that differences in lexical learning and lexical processing are causally implicated in LI. At a proximal level of explanation, a case can be made that sentence comprehension has a lexical basis [76]. On this view, differences in lexical processing have a direct impact on ongoing comprehension. Thus, differences in lexical skill will impact on language processing more generally, with word-level deficits influencing sentence and discourse comprehension. Taking a more developmental perspective, early in development, if grammar emerges from a lexical base [77,78], limitations in lexicon size will be critical. This point is nicely made by Locke, who said of children with deficits in lexical knowledge: 'For them, a lexicon delayed may be a grammar denied' [79, pp. 281–282]. Others have argued that lexical deficits are a consequence of more primary deficits in other aspects of language. Both morphosyntax and phonological short-term memory feature in causal theories that predict lexical sequelae, for review, see [80].

Turning to issues of domain specificity, it might be that apparent language differences stem from non-linguistic sources. For example, there is a sizeable literature exploring the extent to which LI is a consequence of auditory processing deficits and these do seem to be associated with elevated risk of LI, even if they do not play a simple causal role [81,82]; studies have also explored the hypothesis that LI is associated with impairments in processing speed [83]. Parallels to the literature on acquired disorders [84] can be seen if we consider LI stemming from impairments in cognitive control. Children with LI often show concomitant deficits in executive function and these might influence the processes involved in lexical activation or selection, e.g. [85]; developmentally, there is a close relationship between language and the development of cognitive control [86] but once again, cause and effect are difficult to discern: limitations in cognitive control might limit language development but equally, language might also limit the development of cognitive control. The PDH described earlier can also be seen as a domain-general theory, as can differences in associative learning, inherent in McMurray *et al.*'s [42] computational model of word learning.

It is clear that discerning causality is very difficult indeed. The distinction between proximal and distal is not clear cut (see [87] for further discussion) and how relevant pinpointing causality is to our understanding of the lexical nature of LI depends very much on the particular question being asked. If one is interested in underlying causes—what is the nature and origin of LI—then one needs to ask how language difficulties emerge from the genetic and environmental etiological factors that place children at risk for LI. Over recent years, there has been a move away from thinking about causality in terms of one underlying cognitive cause with current theories considering how different cognitive factors might operate together in a probabilistic multi-risk fashion, rather than debating 'the' single or primary underlying cause [88]. This perspective has development at its heart and offers a fruitful way to consider how cognitive-level factors interact and influence each other, as learning happens (see [80,89] for an overview). Within this framework, we can consider how lexical deficits emerge from whatever it is that places a child at risk of LI, while at the same time recognizing that lexical differences themselves will also contribute to the ongoing developmental manifestation of LI.

An understanding of causality within a multiple and probabilistic risk factor model is needed if we are to understand the complexity of gene–brain–behaviour relationship in LI. Equally though, to address theoretical questions in language processing or individual differences in language processing, there is space for more proximal questions to be asked about how words are learned and processed in people with LI. These can be addressed in terms of the cognitive processes involved in language processing (behaviourally or computationally) while remaining agnostic about the etiology and ultimate causes of LI. The empirical and computational work reviewed here demonstrates the utility of this approach.

7. Developmental versus acquired disorders

In keeping with the theme of this special issue, I finish with some reflections on developmental versus acquired disorders. Most obvious is the difference in specificity. I have not tried to differentiate or discuss subtypes of LI. In cases of acquired disorder however, distinctions are made following detailed cognitive testing, most notably between patients who have deficits associated with underlying semantic representations and those whose deficits seem to be one of accessing or retrieving otherwise intact representations, as reviewed by Mirman & Britt [84]. Despite developmental LI being associated with considerable heterogeneity, subtyping even on the basis of a broad distinction between representation and access is problematic, certainly from the evidence base we currently have. Symptom profiles overlap, with many children showing deficits in representation, as indexed by limitations in vocabulary breadth and depth for example. This makes it difficult to assess access in any pure sense: in development, new words are constantly being encountered and learned and these seem to be both weakly represented and hard to access for children with developmental LI. Some children have been reported who seem to show disproportionate difficulties with lexical retrieval—children with word-finding difficulties (e.g. [90]). These children seem to be closest to having something like a specific access problem but even here, interpretation is complicated by the fact that broader language difficulties are often implicated.

Heterogeneity in developmental cases is to be expected, given complex interactions that emerge during language learning [80]. This is certainly the clinical reality, as illustrated by Conti-Ramsden *et al.*'s [91] survey of children attending language units in the UK. They administered a large battery of measures tapping different aspects of language from phonological processing through to discourse comprehension. This identified six different clusters or 'varieties' of LI. However, mapping these clusters onto cognitive models of language processing, with each neatly corresponding to a specific locus, is simply not possible. Heterogeneity is also reflected in current thinking about the causes of LI, with multiple risk factor approaches taking centre stage [88]. As noted earlier, on this view LI is associated with a number of different genetic and environmental risk factors which come together to shape the phenotype in a probabilistic way, interacting with each other, and with other factors that might confer resilience or further risk via co-morbidity. It is important for research to embrace this variation, if we are to understand the nature and causes of LI more fully.

There might though be some lessons to be learned from the approach used in acquired studies. Typically, characterization of the phenotype in developmental disorders is broad, with participants selected on the basis of impaired performance on an omnibus language assessment or a composite language measure. This confirms that children have a functional LI, but it makes comparison across studies difficult. It is also problematic when an omnibus language score is then related to performance on an experimental measure. In general, this is a positive feature as it allows us to look at effects continuously. However, omnibus measures are blunt instruments and beyond characterizing overall severity, they offer little utility. To illustrate: is the lasting competition seen in McMurray *et al.*'s [50] sample associated with language deficits in the same way as resilience to the context effect to block cohort competition is in Brock *et al.*'s [63] study? We simply do not know. As exemplified by a number of papers in this special issue, using measures that are theoretically motivated by models of language processing might allow a closer link to be forged between experimental effect and cognitive profile—and make comparison between studies easier.

Those who study acquired disorders might also benefit from considering developmental work more closely. Developmental studies of LI have embraced individual differences for many years, motivated by the quest to reveal distal causes and explain heterogeneity. Individual differences in domains beyond language (e.g. executive function) have also been considered in some detail. It is interesting to see a more developmental approach characterizing discussion of acquired disorders, as embodied in the primary systems hypothesis for example [92], and in reflections on the nature of the relationship between domain-general factors such as executive function and lexical-semantic processing in patients with acquired disorders [84].

Two important sets of questions need to be addressed by future work, both inspired by developmental issues. First, where do these deficits come from? Are lexical deficits primary, leading to downstream consequences for grammar, or are the lexical deficits themselves a downstream consequence of other deficits, and are these specific to language, or a manifestation of a more general difference in the way that people with LI learn or process information? The second set of questions is more agnostic to underlying causes, but instead asks about the consequences of lexical-level deficits for language processing more generally. Here, there is a need for a tighter link between cognitive model and behavioural effects. The visual world studies reviewed here offer a promising approach for the study of LI, as do studies of lexical learning and consolidation, but much more data are needed. Mirman & Britt [84] note the importance of models that are computationally explicit. This is also true in the developmental domain. A nice example is to consider how our understanding of developmental reading problems has been furthered by computational models [93,94].[2] Relevant to this paper, McMurray *et al.*'s model of word learning [42] offers a new perspective on the interface between learning and processing in typical development, with implications for thinking about developmental disorders in a different way.

In closing, it is clear that some children with LI show lexical weaknesses. Relatively little work has focused on lexical-level issues, but as reviewed here, recent work exploring lexical learning and lexical processing in children with LI has revealed new insights, and in my view at least, has highlighted the need for more research and perhaps even some reconsideration of the role of lexical deficits in understanding the nature of LI more generally.

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Endnotes

[1]Throughout this paper, I use the term LI rather than specific language impairment (SLI) in recognition of the fact that not all studies differentiate between specific and non-specific LI. Moreover, language and non-verbal skills are continuous and correlated dimensions (see [1,2] for discussion). LI is not uncommon, with approximately 7% children meeting criteria for SLI [3] and many more showing non-specific LI, or language difficulties associated with other developmental conditions such as autism or dyslexia [4].

[2]An interesting point of detail, highlighted by Bob McMurray: Harm and colleagues [95,96] found that changing decay rate in the Plaut *et al.* model [94] provided a good fit to data from children with developmental dyslexia, much like McMurray *et al.*'s fit between TRACE and data from LI, as discussed earlier.

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