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# Working memory and developmental language impairments

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Abstract

Children with developmental language impairments (DLI) are often reported to show difficulties with working memory. This review describes the four components of the well-established working memory model, and considers whether there is convincing evidence for difficulties within each component in children with DLI. The emphasis is on the most demanding form of working memory that draws on central executive (CE) resources, requiring concurrent processing and storage of information. An evaluation of recent research evidence suggests that, not only are children with DLI impaired on verbal CE measures, but they also show difficulties on non-verbal CE tasks that cannot be assumed to tap language. Therefore, it seems increasingly likely that children with DLI show domain-general CE impairments, along with their more established impairments in verbal short-term memory. Implications for potential working memory interventions and classroom learning are discussed.

In recent years there has been much interest in the cognitive profile of children who have developmental language impairment (DLI), a disorder with a prevalence in school children of 3-6% (Hulme & Snowling, 2009). These children fail to make adequate progress in language development (phonology, vocabulary, grammar, morphology) despite the absence of underlying intellectual, neurological, social or emotional impairment (e.g., Leonard, 2014). However, the heterogeneity of DLI presents considerable challenges because individual children can have very different language profiles (e.g., phonology, syntax, receptive/expressive language skills) that may change with age and development. For example, Conti-Ramsden, Crutchley, and Botting (1997) used cluster analysis to identify subgroups of children who showed different profiles within a DLI sample aged 7 years. Three key bands of children were evident: those with expressive difficulties; those with receptive and expressive impairments; and those with relatively good expressive skills but poor receptive and pragmatic language. These subgroups were also evident a year later. However, the membership of subgroups was not stable over time and around 50% of children changed profiles (Conti-Ramsden & Botting, 1999). Furthermore, the terminology used to describe children for whom language impairments are the major concern is currently under review (e.g., Bishop, 2014; Reilly et al., 2014), so the term DLI was chosen to emphasise that this is a developmental disorder involving a significant degree of primary language impairment.

The role of non-linguistic factors in DLI has been of increasing interest, and this is reflected in emerging evidence that working memory difficulties are important for many of these children, alongside their structural language deficits. This approach to consider wider factors has affected theoretical stances (Botting & Marshall, in press), the diagnostic descriptions of children with language impairment (Bishop, 2014; Reilly et al., 2014), and the types of intervention evidence that is available (Holmes et al., 2015; Wener & Archibald, 2011). In this article, we review the current state of knowledge regarding working memory and DLI.

*Working memory*

Working Memory describes a set of cognitive functions involved in the temporary manipulation and storing of information during thinking, reasoning and remembering tasks. There are a number of different conceptualisations of working memory (e.g., Cowan, 2005; Engle, Toholski, Laughin, & Conway, 1999), but all acknowledge that working memory is *limited* such that only a certain amount of information may be temporarily held and manipulated. One of the most influential models is the Working Memory Model (Baddeley & Hitch, 1974; Baddeley, 2000), which has the advantage of providing a clearly organised system of interacting components assumed to underpin everyday cognitive tasks requiring storage and processing of information during complex thought and cognitive operations. Further, it is often used as the theoretical framework for experimental studies on children with DLI, which makes is particularly helpful in understanding their working memory strengths and weaknesses.

The latest version of the working memory model (Baddeley, 2000) consists of four components that work together to enable us to deal with current thinking and memory demands. The most important component is the ‘central executive’, which focuses, divides and switches attention, in order to direct resources within the working memory system appropriately. Researchers believe that the central executive component is involved in a constellation of skills that enable us to carry out complex, novel and demanding tasks, for example: to hold in mind and process different types of information; to cognitively plan; to problem solve; to switch strategies when required; to generate new solutions; and to ignore irrelevant information. These types of skills are often referred to as executive functioning (EF, e.g. Diamond, 2013), and the specific working memory tasks that draw on central executive resources are usually described as central executive (CE) tasks. There are also two passive storage systems within the working memory model that store verbal and visual/spatial information respectively (the 'phonological loop' and the 'visuospatial sketchpad') for brief periods of time. These storage systems underpin verbal short-term memory (VSTM) and visuospatial short-term memory (VSSTM). The final component of the model, the 'episodic buffer', is less well understood, but has features that make it relevant for children with DLI: (1) it links the working memory system to all stored long-term knowledge (e.g., language knowledge that can be used to support working memory); (2) it integrates or binds information together from all components to create a unified and coherent experience; and (3) it offers some extra storage capacity that is not dependent upon the perceptual features of the input.

A number of working memory tasks have been developed to assess different components of the working memory system (although it must be acknowledged that tasks can draw on more than one component), and these will be highlighted where relevant. The term 'working memory' has also been used in the literature to describe CE tasks, i.e., those tasks that require central executive resources to direct and control attention. Such tasks require continuous updating and/or manipulation of information in immediate memory, rather than just simple (passive) storage of information as would be the case for VSTM or VSSTM.

Usually, CE tasks draw on either VSTM or VSSTM storage systems, but have the added requirement of central executive and episodic buffer resources.

CE tasks can include *complex memory span* (e.g., Listening/Reading span whereby a true/false judgement is made about a heard or read sentence and the final word of that sentence must be recalled – increasing the numbers of sentences presented increases the demands of this processing/storage task, e.g. Siegel & Ryan, 1989), *backwards span tasks* (the assessor points to a series of blocks in order/or reads out a list of digits, and children must respond by pointing to/repeating the list in reverse order – this calls for processing resources to reverse the list and memory to retain the specific items), *N-back tasks* (judgements must be made about whether a particular stimulus in a series has been encountered previously, either 'one item back' or 'two items back', calling for continual updating of current stimulus details, e.g., Im-Bolter, Johnson, & Pascual-Leone, 2006), and *self-ordered pointing tasks* (a set of items are presented repeatedly in different random orders/locations and the participant must point to a different item on each presentation, requiring constant updating of items that have already been chosen, e.g., Archibald & Kerns, 1999).

Why does working memory receive so much attention in the literature? Diamond (2013) argues that working memory "is critical for making sense of anything that unfolds over time, for that always requires holding in mind what happened earlier and relating that to what is happening now" (pp. 142-143). Diamond emphasises that because of this, working memory is particularly relevant for understanding spoken language and written texts. Educational progress, especially in terms of accessing the curriculum, is also linked to working memory (e.g., Gathercole, Pickering, Knight, & Stegmann, 2004; St Clair-Thompson & Gathercole, 2006; van der Ven, Kroesbergen, Boom, & Leseman, 2012), and there is increasing interest in whether interventions that target skills can lead to meaningful improvements in academic achievement and other cognitive skills (for a review see Melby-Lervåg & Hulme, 2013).

*Verbal and visuospatial short-term memory and language impairments*

Verbal short-term memory (VSTM) refers to the ability to repeat a short list of verbally presented items immediately in the correct order (usually assessed by asking the child to repeat a list of digits or words, or repeat nonwords). Theoretically, it is argued that weaknesses in holding in mind verbal information over short periods of time could negatively impact the child's ability to create accurate and stable long-term representations for new words and, therefore, affect vocabulary development (Gathercole & Baddeley, 1990). Further, poor verbal storage makes it hard to retain grammatical details in spoken language that affect meaning, compromising the child's language comprehension and receptive grammar (Montgomery, Majimairaj, & Finney, 2010). In support of this position, weak VSTM is one of the most consistent findings in the literature on children with DLI (e.g., Archibald & Joanisse, 2009; Bishop, North, & Donlan, 1996; Botting & Conti-Ramsden, 2001; Chiat & Roy, 2007; Gathercole & Baddeley, 1990; Lum, Conti-Ramsden, Page, & Ullman, 2012; Marton & Schwartz; 2003; Pickering & Gathercole, 2004; Vugs, Hendriks, Cuperus & Verhoeven, 2014).

However, there is considerable variability between studies in terms of age levels included and degree of VSTM impairment reported. Meta-analyses allow greater power to detect important differences between groups by combining smaller studies and deriving a common unit of difference, the effect size (an effect size of 1 would indicate that there is a one standard deviation difference between the groups). Graf Estes, Evans, and Else-Quest (2007) considered VSTM differences (measured using nonword repetition tasks) between children with DLI and typical children in 23 separate studies that included 549 children with DLI and 942 typical comparisons. The language-impaired groups had to meet the criteria for DLI, namely impaired expressive and/or receptive language skills and normal nonverbal intelligence. A substantial and clinically meaningful difference in VSTM was found between the DLI and typical groups with a mean effect size of 1.27. Interestingly, effect sizes did not vary with the age of the children, suggesting that VSTM impairment was invariant with age. Given the strength of the evidence for verbal storage difficulties in those with DLI, weak VSTM has been suggested as a ‘marker’ for DLI (Bishop et al, 1996; Archibald & Joanisse, 2009). Further work showing that poor VSTM is associated with slow language development in typical children (e.g., Adams & Gathercole, 1995; Gathercole, Willis, Emslie, & Baddeley, 1992; Gathercole, 2006; Gathercole & Baddeley, 1989; Michas & Henry, 1994; Stokes & Klee, 2009) adds to the evidence that verbal storage is critical for the developing language system.

Visuospatial short-term memory (VSSTM) refers to the ability to hold in mind and report back immediately spatial or visual information/details (e.g., usually assessed by asking the child to recall patterns or spatial positions). Difficulties with visuospatial storage in children with DLI may not be expected if their impairments are exclusive to language, however, given evidence for non-linguistic factors associated with DLI (e.g., Bishop, 2002; Johnston & Ellis Weismer, 1983), evaluating this aspect of working memory contributes to debates around the specificity of DLI. Many studies of children with language difficulties have found no evidence for VSSTM impairments (e.g., Archibald & Gathercole, 2006; Henry, Messer & Nash, 2012a; Hutchinson, Bavin, Efron, & Sciberras, 2012; Lum, Conti-Ramsden, Page, & Ullman, 2012; Petruccelli, Bavin & Bretherton, 2012), although this is not exclusively the case (for reports of VSSTM difficulties in children with DLI see Bavin, Wilson, Maruff, & Sleeman, 2005; Hick, Botting & Conti-Ramsden, 2005; Hoffman & Gillam, 2004; Leclercq, Maillart, Pauguqy, & Majerus, 2012; Vugs, Hendricks, Verhoeven, & Cuperus, 2014).

Given the ambiguity in the literature on visuospatial storage, Vugs, Cuperus, Hendricks and Verhoeven (2013) carried out a meta-analysis of 21 separate studies of VSSTM in children of varying ages with DLI, encompassing 32 different measures of VSSTM (e.g., recall of shapes, pictures, dots, blocks, hand movements). Contrasting VSSTM in typical children and those with DLI, the mean effect size was 0.49, which is classed as ‘medium’ in size (Cohen, 1988). The effect size was not influenced by the age of the participants, but inclusion criteria for DLI were important: larger effect sizes were reported for studies defining DLI as requiring difficulties in two or more (0.70) as opposed to only one (0.32) domain of language. Vugs et al. (2013) concluded that visuospatial storage difficulties in children with DLI were smaller in magnitude (i.e., half a standard deviation) than verbal storage difficulties (over one standard deviation in the Graf Estes et al., 2007 meta-analysis reported above). It is possible that children with DLI have difficulties, in particular, with visual complexity (Leclercq et al., 2012), but further research is needed in this area. More generally, the evidence for weaker VSSTM in children with DLI calls into question the specificity of language impairments in children with DLI – and this is an issue that we will come back to.

One key issue in evaluating research on VSSTM is that evidence can sometimes be confounded with verbal content in the ‘non-verbal’ tasks themselves, or the possibility of using a verbal strategy (see Botting, Psarou, Caplin, & Nevin, 2013, for an exploration of this issue). In such a case, VSSTM difficulties could reflect poor or inefficient use of verbal mediation for the visuospatial information (e.g., Archibald & Gathercole, 2006). However, most VSSTM tasks have been designed to discourage verbal strategies, and Vugs et al. (2013) argued that the absence of age differences in their meta-analysis speaks against this possibility – verbal coding during visuospatial tasks is unlikely in children under seven years, and age differences between younger and older children were not found.

*The episodic buffer and language impairments*

The episodic buffer is a multi-modal storage system in which information from short-term stores (VSTM, VSSTM) and long-term knowledge (e.g., language knowledge) is integrated or bound into coherent chunks and stored temporarily (Baddeley, Hitch, & Allen, 2009). Its inclusion in the revised working memory model (Baddeley, 2000) acknowledged the key role that language and other types of knowledge play in supporting working memory performance. A commonly used measure of verbal episodic buffer functioning is the prose recall task (e.g., Baddeley & Wilson, 2002), which requires the utilisation of long-term knowledge about the structure of language, vocabulary, content of the passage and the structure of typical narratives or scripts. This information is then integrated with information stored in VSTM, and ‘‘modality free’’ representations held in the episodic buffer. The episodic buffer is hypothesised to create a novel episode, by automatically combining primed or activated representations from long-term memory with information in

VSTM, drawing on central executive resources to maintain this new representation (Baddeley & Wilson, 2002).

Sentence recall tasks, which involve repeating sentences immediately after hearing them, have also been used to assess episodic buffer functioning (e.g., Alloway, Gathercole, Willis, & Adams, 2004; Baddeley et al., 2009), and they are argued to draw similarly on the episodic buffer and VSTM (Baddeley et al., 2009). The limited available research on the episodic buffer in children with DLI concerns sentence recall, and we might expect performance on this task to be impaired, given their VSTM difficulties and language weaknesses. In fact, overall performance on measures of sentence recall is impaired in children with DLI (e.g., Archibald & Joanisse, 2009; Hutchinson et al., 2012; Petruccelli, Bavin, & Bretherton, 2012). However, further research is needed to confirm which other components in the working memory system might affect performance, and exactly which aspects of language knowledge are involved. Polišenská, Chiat, and Roy (2015) have argued that the ability to repeat sentences is dependent on familiarity with morphosyntax and lexical phonology, and less so on semantics or prosody. Another important area for future research is to investigate visuospatial measures of the episodic buffer (e.g., the binding of visual and spatial features) and compare them to verbal measures in children with DLI, as this could reveal important information about the specificity of language difficulties. Given the sparse research in this area, conclusions about the episodic buffer in children with DLI must remain tentative.

We now turn our attention to tasks which load on the central executive component of the working memory system, i.e., verbal or visuospatial CE tasks that require the concurrent processing/manipulation and storage of information.

*Central Executive (CE) working memory and language impairments*

There has been increased interest in CE task performance in developmental disorders generally (e.g., Geurts, Verte, Oosterlaan, Roeyers, & Sergeant, 2004; Gioia, Isquith, Guy, & Kenworthy, 2000) and specifically how it relates to language (e.g., Henry, Messer & Nash, 2012b; Im-Bolter, Johnson & Pascual-Leone, 2006; Vugs et al., 2014). CE difficulties have been highlighted as a possible underlying cognitive mechanism for the functional behaviours presented in several other developmental disorders that overlap with DLI, particularly ADHD and ASD (Barkley, 1997; Jahromi, Bryce, & Swanson, 2013). The presence of CE deficits has direct clinical and educational implications in children with DLI because of its association with key classroom skills such as understanding and acting on instructions, and any form of verbal problem-solving that requires the manipulation and recall of key information.

Partly as a result of these factors, there have been over 50 papers published on CE and children with DLI since 2000. Table 1 summarises the most recent articles published in peer-reviewed English language journals from 2010 onwards. Although we performed a systemised search of the literature, this list is not exhaustive and focuses on studies where CE, working memory or executive functions have been explicitly mentioned in relation to children with DLI (some look at relationships between CE and language, others compare DLI and typically developing [TD] groups). Only studies that assessed CE using generally accepted and comparable measures were included (in fact, many papers explicitly mention the working memory model). Commonly used inclusion criteria for DLI (NVIQ>85, language<-1SD/<-1.25 on a composite/core measure, usually CELF-4, or impaired performance on at least two language measures), were often used, but not exclusively so. Thus, relevant inclusion criteria are included in Table 1.

*Table 1: Papers on CE and developmental language impairments since 2010*

| **Authors** | **Year** | **Theme** | **Population** | **Key Findings** |
|---|---|---|---|---|
| Lukács, Ladányi, Fazekas, & Kemény | 2016 | WM & language | DLI & TD<br>Age 7 (only mean age provided)<br>(NVIQ>85; DLI = at or below -1.25SD on at least two language measures) | DLI<TD on CE tasks<br>(Some evidence of greater discrepancy on verbal than non-verbal CE tasks) |
| Vugs, Knoors, Cuperus, Hendriks, & Verhoeven | 2015 | WM & language; Structure of WM | DLI & TD<br>Age 4-5<br>(NVIQ>85; DLI = at or below -1.25 SD on two language measures) | WM structure did not differ overall between groups, but verbal and visuospatial CE tasks may be *more* differentiated in children with DLI.<br>Verbal CE related strongly to receptive and expressive language in DLI. |
| Holmes et al. | 2015 | WM intervention (Cogmed) | Low language abilities<br>Age 8-11<br>(NVIQ unrestricted; | Significant gains in VSSTM, but gains were not significant in CE or VSTM (although effect sizes were substantial). |

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| | | | LLA = below -1SD on two language tests) | |
| Henry, Messer & Nash | 2015 | WM & language | DLI & TD<br>Age 8-14<br>(NVIQ>85; DLI = at or below -1SD on three or four CELF-4 UK subtests) | Verbal fluency skills were related to language ability. Verbal CE was not a strong predictor of verbal fluency when language ability was controlled. |
| Frizelle & Fletcher | 2015 | WM & language | DLI, age-matched TD (Age 6-7) and language-matched TD (Age 4)<br>(NVIQ>85; DLI = below -1.25 SD on CELF-4 UK) | DLI<TD on verbal CE.<br>For DLI, verbal CE was related to production of more difficult relative clauses (in a sentence recall task). |
| Vugs, Hendricks, Cuperus, & Verhoeven | 2014 | WM, EF and language | DLI & TD<br>Age 4-5<br>(NVIQ>85; DLI = at or below -1.25 SD on two language measures) | DLI<TD on verbal and non-verbal CE. |
| Noonan, Redmond, Archibald | 2014 | WM & language | DLI & TD<br>DLI+WM & TD<br>Age 5-8<br>(NVIQ unrestricted; DLI = <86 on CELF-4 UK Composite Language Score) | DLI<TD on grammaticality judgements regardless of WM load.<br>DLI+WM<TD on grammaticality judgements with high WM loads only.<br>Language impairment *and* CE |

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| | | | | important for grammaticality judgements. |
| Vugs, Cuperus, Hendriks, & Verhoeven | 2013 | Meta-analysis of non-verbal WM | DLI and TD<br>Approx. 3-14<br>(NVIQ varied; DLI = below -1 SD on either one or two language tests) | DLI<TD for non-verbal CE (and VSSTM) |
| Poll, Miller, Mainela-Arnold et al. | 2013 | WM & language | TD + DLI mixed ability group<br>Age 6-13<br>(NVIQ>75; CELF Core Language Score range 60-124) | Verbal CE was independently related to sentence imitation; speed of processing was sometimes independently related to sentence imitation. |
| Archibald & Joannisse | 2013 | WM & Language | DLI, WM impairment & TD<br>Age 8<br>(NVIQ unrestricted; DLI = <86 on CELF-4 UK Composite Language Score) | CE (composite of verbal and non-verbal) related strongly to word list learning and paired associate learning. |
| Duinmeijer, de Jong & Scheper | 2012 | WM & language | DLI & TD<br>Age 6-9<br>(NVIQ unrestricted; DLI = diagnosis of severe language disorder) | DLI<TD on verbal CE.<br>Verbal CE related to *retelling* plot elements but not to *generating* plot elements in narrative tasks. |
| Henry, Messer & | 2012 | Nature of WM/ | DLI, Low language | DLI=LLF<TD on verbal and |

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| Nash | | WM & language | functioning & TD<br>Age 6-14<br>(NVIQ>85; DLI = at or below -1SD on three or four CELF-4 UK subtests) | non-verbal CE.<br>Same findings even after controlling for verbal and non-verbal abilities. |
| Maniela-Arnold, Misra, Miller, Poll & Park | 2012 | WM & language | Mixed language abilities<br>Age 6-13<br>(NVIQ>77; CELF Core Language range 60-124) | Language segmentation ability (elision) predicted verbal CE (but processing speed did not). |
| Petruccelli, Bavin & Bretherton | 2012 | Nature of WM / WM & language | DLI, resolved late talkers (RLT) & TD<br>Age 5<br>(NVIQ>85; DLI = at or below -1.25SD on CELF-P2 Expressive and/or Receptive Language Scales) | DLI=RLT=TD on one measure of verbal CE (backwards digit recall), although authors argued that task difficulty was too high and reduced discriminability between groups. |
| Hutchinson, Bavin, Efron & Sciberras | 2012 | Nature of WM | DLI, ADHD, DLI+ADHD & TD<br>Age 6-9<br>(NVIQ>85; DLI = at or below -1.25SD on CELF-4 Expressive and/or Receptive Language Scales) | DLI=ADHD=DLI+ADHD<TD on 2 out of 3 verbal CE tasks. |

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| Freed, Lockton & Adams | 2012 | Nature of WM | DLI & Pragmatic LI<br>Age 6-10<br>(NVIQ≥5th centile; DLI = impaired scores on at least one language measure) | DLI=PLI on verbal and non-verbal CE.<br>But for DLI, STM=CE whereas for PLI, STM>CE. |
| Lum, Conti-Ramsden, Page, & Ullman | 2012 | WM and other memory systems | DLI & TD<br>Age 8-11<br>(NVIQ>85; DLI = at or below -1.25SD on CELF-4 UK Core Language Score) | DLI<TD on verbal CE measures even after language was used as a covariate. |
| Wener & Archibald | 2011 | Intervention | DLI+WM, DLI & TD<br>Age 7-9<br>(NVIQ unrestricted; DLI = below -1SD on CELF-4 Composite Language Score) | Domain-specific treatment effects were found. |
| Lum & Zarafa | 2010 | WM & auditory processing | DLI & TD<br>Age 8-11<br>(NVIQ>85, DLI = below -1SD on CELF-4 Core Language Score) | DLI<TD on auditory processing and verbal CE.<br>DLI=TD on auditory processing when verbal CE controlled. |

*Overall findings from research thus far*

The overall message from these papers is that children with DLI show difficulties with CE tasks: of the ten papers including direct DLI/TD group comparisons, nine found significant differences in favour of TD children. Group differences did not vary with the ages of the participants included (4 through 14 years), suggesting a developmentally consistent pattern of CE impairment, at least in this age range. Further, nine of the papers included commonly accepted inclusion criteria for DLI, including cognitive referencing, but the one paper that did not, still found a DLI CE impairment (Duinmeijer et al., 2012). Somewhat more specific questions will now be considered: (1) Do these studies reveal anything about the relationship between memory and language (beyond group differences)?; (2) Are CE difficulties in children with DLI domain-general or more specific to verbal tasks?; and (3) What is the effectiveness of intervention?

*1) The relationship between CE working memory and language*

Many of the studies explored the relationships between aspects of language and CE. The findings underline the strong connections between verbal CE, in particular, and language. For example, Vugs et al. (2015) reported that although the overall structure of working memory was not different in 4-5-year-old children with DLI and TD, there was some evidence that a difference emerged on CE tasks - the shared variance between verbal and visuospatial CE was higher in the TD (72%) than the DLI group (5%), implying more differentiation between CE domains in those with DLI. Further, Vugs et al. found that verbal CE was strongly related to both receptive and expressive language in the DLI group, suggesting verbal CE is involved in the acquisition of a broad range of linguistic skills. However, further research will be required to assess the structure of working memory and the relationships between CE and language in older children with DLI; developmental changes in the degree and nature of language impairment could change the underlying structure of working memory and its relationship with language.

Other papers reported relationships between verbal CE and sentence imitation (Poll et al., 2013), verbal CE and language segmentation (elision) (Mainela-Arnold et al., 2012), and composite measures of CE and the ability to retell plot elements in narrative tasks (Duinmeijer et al., 2012). Further, Lum and Zarafa (2010) showed that verbal CE was strongly related to measures of auditory processing difficulties (the Test for Auditory Processing Disorders in Children-Revised, SCAN-C; Keith, 2000), with a correlation of .77. These authors argued that the SCAN-C was, therefore, not primarily a measure of the perceptual stages of auditory processing, and that higher-level cognitive processes such as verbal CE are substantially implicated in performance. Finally, although verbal CE was reported to be related to verbal fluency performance, it did not remain a strong predictor when language skills were controlled (Henry et al., 2015), suggesting that verbal fluency and language ability are overlapping constructs.

Frizelle and Fletcher (2015) found that, for children with DLI, the ability to repeat complex sentences (incorporating relative clauses) was related to verbal CE. Such relationships were not seen in typical children - for them, it was PSTM that was associated with relative clause constructions. These findings suggest that children with DLI rely on verbal CE for repeating complex syntactic structures, whereas typical children find these tasks less cognitively demanding and can rely on passive verbal storage. Noonan et al. (2014) provided an elegant set of findings to establish the unique and separate influences of CE and linguistic competency on a grammaticality judgment task. The results suggested that children with DLI may have a specific deficit in grammatical learning, whereas those with co-occurring DLI *and* working memory difficulties learn grammatical rules and structures but make errors when the processing load imposed by the context exceeds their working memory capacity.

Finally, it is interesting to note that more traditional memory measures may draw directly on language skills. Archibald and Joanisse (2013) reported that word list learning and paired associate learning were related to a composite measure of CE. Overall, performance on CE tasks (particularly verbal CE tasks) seems to be linked to various measures of language, although the direction of causality cannot be established, and the complexity of the findings reflects uncertainties surrounding our understanding of how these skills are linked.

2) *Domain general or domain specific deficits in DLI?*

Some have suggested that CE deficits in children with DLI are domain general. That is, children with DLI show difficulties regardless of whether the task components (i.e., the processing and storage requirements) are in the verbal or non-verbal domain. However, in the papers detailed here, verbal CE difficulties were more commonly assessed and reported. Whilst verbal CE difficulties may be expected in those with DLI given their language weaknesses (e.g., Archibald & Gathercole, 2006a; Ellis Weismer, Evans, & Hesketh, 1999; Lum et al., 2012; Marton & Schwartz, 2003; Montgomery, 2002), non-verbal difficulties could also be prevalent. There may be cognitive difficulties in DLI that interfere with concurrent processing and storage in any domain, or language deficits could interfere with all types of CE performance.

In this regard, the non-verbal CE findings become of particular relevance to assess whether such difficulties are characteristic of those with DLI. Although some studies have failed to find non-verbal CE difficulties in children with DLI (e.g., Archibald & Gathercole, 2006b), others have reported significant differences (Im-Bolter et al., 2006; Marton, 2008), and a meta-analysis that included seven separate studies reported significant difficulties for those with DLI, with a moderate effect size of .63 (Vugs et al., 2013). Further, when CE tasks in both domains are included in the same study, evidence for both verbal and non-verbal CE difficulties often emerges. For example Henry et al. (2012b) showed that children with DLI performed more poorly than peers on both verbal and non-verbal CE tasks, even after controlling for general verbal and non-verbal abilities. Vugs et al. (2014) also found large differences between typical children and those with DLI on six different CE tasks, half of which were in the verbal and half in the non-verbal domain (although see Lukács et al., 2016).

3) *Intervention studies involving CE and low language skill*

There has been much interest in the recent research literature concerning the possibility of improving CE in typical children and those with various developmental difficulties and/or low memory skills (see Melby- Lervåg & Hulme, 2013, for a review). However there have been few investigations regarding CE interventions for children with DLI. Some important exceptions exist. For example, Holmes et al. (2015) investigated whether Cogmed Working Memory Training was an effective intervention for children with low language abilities. This intervention targets a number of areas of working memory and is argued to improve the neural efficiency of the brain networks that underlie working memory via intensive practice. Homes et al. reported some promising results: 12 children with low language abilities made significant gains on VSSTM, VSTM and CE, and their gains were as great as those made by 15 typically developing comparisons. The limitation in this study was that, after corrections for multiple comparisons, many training gains (with the exception of VSSTM) were rendered non-significant, despite large effect sizes. A further interesting finding was that children with the lowest initial verbal IQs made the greatest gains in VSTM. Wener and Archibald

(2011) also demonstrated in a small scale study that most children with DLI (n=5 out of 7) responded well to an intervention that included four elements, one being an CE task (N-back task), showing gains in performance on a grammatical task (‘word structure’ from the Clinical Evaluation of Language Fundamentals) that were retained four months post-treatment. This was true for children who initially had poor working memory scores as well as DLI, *and* those with DLI whose working memory scores were not of concern.

Clearly, more research with greater power to detect significant training gains (larger sample sizes) is required in this area. Another key issue is the type of working memory skills to focus on. Several components of working memory seem to be impaired in children with DLI, but individual profiles may vary considerably. Given the links between verbal CE and language outlined earlier (and evidence that verbal CE is the best predictor of language – Vugs et al., 2015), this may be an effective area to target in working memory interventions. However, it is not clear whether working memory difficulties in children with DLI are a secondary consequence of language difficulties, and there is considerable complexity involved: difficulties may include perceptual problems; broader cognitive difficulties; as well as working memory problems (e.g., Gathercole & Holmes, 2014). Nevertheless, given the potential benefits for children with DLI, further working memory intervention studies would be valuable.

*Implications for practice*

The review presented here suggests that professionals working with children who have DLI should have some training and awareness of possible working memory difficulties present in this group. Although most existing evidence relates to poorer VSTM and verbal CE, emerging evidence indicates there may be wider difficulties with VSSTM and visual CE. However, as DLI is a very heterogeneous disorder, there is likely to be considerable variation in the working memory profiles of these children. For this reason, it is important to assess children individually on all components of working memory, as this can guide interventions by identifying strengths and weaknesses.

Beyond considering working memory training interventions, there are some classroom-based strategies that could help overcome working memory difficulties. For children with DLI identified as having CE difficulties, compensatory strategies such as reducing the CE elements/loads present in classroom tasks (e.g., by presenting everything in small steps/stages), providing extra memory support using flashcards on the child's desk containing key information for challenging cognitive tasks (i.e., to reduce the need to *store* information as well as manipulate it), and using mind maps to represent complex information, might be helpful. For children with VSTM impairments, shortening verbal instructions, providing supportive visual cues, limiting distracting/background noise when talking to children, and encouraging the use of non-verbal responses may be helpful. For children with VSSTM difficulties, reducing the visual complexity of information (e.g., diagrams, graphs) could be achieved by colour-coding, or using a 'stepped' presentation of complex images such that each new step adds just one new visuospatial element that the child can integrate before more is added. For these children, visually-based compensatory strategies may be less effective, and it will be important to determine if strengths in other working memory components could underpin alternative interventions. More broadly, children with working memory difficulties can benefit from cognitive and learning tasks that are designed to tap into areas extensive knowledge (e.g., football knowledge, Schneider, Körkel, & Weiner, 1989) to increase the support offered by long-term knowledge via the episodic buffer. Another promising technique involves training children in effective mnemonic strategies to boost performance (e.g., rehearsal, visual imagery, creating stories, grouping – see Gathercole & Holmes, 2014). These approaches may enable children with language difficulties to perform more similarly to their peers on everyday learning tasks.

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