Phonological Encoding and Verbal Rehearsal Strategies in Children with Developmental Language Disorder

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Declaration

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Abstract

Background: To support children who have Developmental Language Disorder (DLD) with effective interventions, it is important to understand the nature of their difficulties. Working memory difficulties are found in most children with DLD. A key element of the working memory system is phonological encoding, the process of transforming a visual stimulus (such as a word or picture) into a verbal label. Phonological encoding is important for effective working memory, as verbal material is easier to remember, is strongly implicated in word learning, and can be measured through the presence of the 'phonological similarity effect' (PSE). Little is known about the PSE in children with DLD. The aim was to investigate whether phonological encoding and children's use of verbal rehearsal strategies, used to support this process, were reduced in children with DLD compared to their typically developing (TD) peers. In addition, several processes that are known to be associated with working memory were also investigated, to consider if they predicted phonological encoding abilities.

Method: Children aged 6-7 (*n*=69) and 9-10 years (*n* = 63), some typically developing (*n*=59) and some with DLD (*n* = 73) played a laptop-based working memory game. Pictures of common objects were presented visually, and recall was via a pointing method, so the task could be carried out without using phonological encoding. Children recalled which pictures they had seen, in serial order, by tapping images of them on the screen. This was repeated for two lists of pictures: those with either phonologically similar or phonologically dissimilar names. The discrepancy between recall of each of those lists was used to calculate the 'PSE' and infer the presence of phonological encoding. The logic was that, if phonological encoding were used, confusion would arise in remembering the names of items that were phonologically similar. Afterwards the children repeated the task at their maximum memory span levels and were asked to self-report which, if any, verbal rehearsal strategy they used to help them remember the pictures.

Results: Children with DLD at both ages showed a significantly reduced PSE compared to their TD peers, and this effect was found even when using a proportional score to take account of children who had a low memory span. In addition, children with DLD reported using 'complex' verbal rehearsal strategies less often than their TD peers. There was a lack of significant associations between measures known to correlate with working memory and PSE, in children with or without DLD.

Conclusions: In this investigation, children with DLD showed a significantly lower PSE and significantly reduced use of verbal rehearsal strategies than TD peers. Both findings suggests that they are less likely to use phonological encoding than their TD peers.

Implications: The research provides new findings which could have implications for future clinical practice e.g., language interventions and the adaptation of classrooms to better support children with DLD and working memory difficulties.

CHAPTER 1

Phonological Encoding and The Working Memory Model

1.1 Overview of the thesis

Working memory has been investigated for many decades, and the process of what happens 'inside our heads' when remembering materials for shorter and longer periods of time is fascinating and mysterious. While much work has occurred into 'inner speech' to attempt to pin down the internal monologue that is used for problem solving and recall, this thesis is concerned more specifically in a form of inner speech which can be used to help remember verbal material for short periods of time. This process is known as 'phonological encoding'. Phonological encoding is the process allowing items that have verbal labels (e.g. pictures of common objects) that are presented visually to be labelled internally to aid recall: "hearing" the label in one's head for an object that is being observed, but without speaking it aloud (Henry, Messer, Luger-Klein, & Crane, 2012). This means that phonological encoding can be used to translate pictorial information into a verbal code, which can then be repeated over and over again to keep it in mind. This process is used for working memory tasks (to hold information in mind whilst 'doing something' with it) and is particularly important in word-learning, as a new label is processed and learned to create a phonological representation which can then be retrieved in future. In addition, phonological encoding allows one to produce speech sub-vocally and direct it to oneself (Jones, P. E., 2009)

As a result, questions arise about those who do not demonstrate typical language development – namely, children with Developmental Language Disorder (DLD) – and what differences may occur in their development of and use of phonological encoding and other 'inner speech' processes, and whether these are implicated in the displayed language difficulties themselves.

Language is crucial for certain parts of the working memory system (Gathercole & Baddeley, 1990). There is substantial evidence for working memory and other types of memory difficulties in children with DLD: working memory challenges are often seen as a key aspect of DLD, and is regarded as a potential clinical marker of the disorder (Archibald, Gathercole, & Alloway, 2006). A difference in the development or use of phonological encoding could, therefore, be present in this population. As there is virtually no research to date on the emergence and development of phonological encoding in children with DLD, these issues form the key questions investigated in the current thesis.

Thus, this thesis is concerned with the development and use of phonological encoding in children with DLD. The current chapter will start with an extended discussion on the definition of key terms that have emerged from existing literature on inner speech, verbal mediation, and phonological encoding development; carefully explaining the differences between these terms. It will then focus on phonological encoding, outlining how phonological encoding can be measured; and go on to describe current understanding of the development of phonological encoding in typically developing children. The following introductory chapters will introduce each of the three research questions addressed in this thesis:

> RQ1) Do children with DLD have difficulties with phonological encoding compared to age and non-verbal IQ matched typically developing children?
>
> RQ2) Does the development of verbal naming and rehearsal strategies follow the same pattern in children with DLD between 6 and 10 years as their age and non-verbal IQ matched typically developing peers?

RQ3) Are there similar relationships in the DLD and TD groups between phonological encoding and the following variables: reaction time, RAN, speech rate, reading and expressive vocabulary?

Chapter 2 will consider the development of working memory and phonological encoding in children with DLD, a condition which occurs when an individual has specific difficulties with language development without any other known cause[1]. Chapter 3 will address the use of inner speech as a memory strategy, including verbal rehearsal: what it is; how it develops; what is known about this in children with DLD and how it can be measured. Chapter 4 will cover some processes associated with phonological encoding and discuss how these may contribute to PSE development, and hypothesised differences in children with DLD.

1.2 What is Phonological Encoding?

Phonological encoding, the process of producing a verbal label for a visual stimulus, is hypothesized to take place within a sub-component of the working memory model known as the phonological loop. This thesis focuses on Baddeley's Working Memory Model (Baddeley, 2010; Baddeley & Hitch, 1974), which is a well-established and influential model that has underpinned a great deal of research on adults and children for over four decades.

Working memory involves the ability 'to hold in mind information, in the face of distractors, in order to guide behaviour' (Jarrold, 2017). It is usually conceptualised as a multi-component system that allows us to temporarily store information in an active state (Cowan, 1988), as well as to manipulate this information as necessary during thinking and reasoning tasks. Working

[1] DLD was previously known as Specific Language Impairment (SLI) and, as a result, much literature refers to SLI rather than DLD (Bishop, Snowling et al., 2016b). For clarity, SLI/DLD will be used when referring to the condition as described in work published before DLD became common use.

memory is responsible for storing and manipulating short-term information (Archibald, 2017). Working memory is used during both day-to-day familiar tasks, as well as during complex tasks that require more effort. Working memory deals with the 'now' and underlies all higher order thinking and reasoning tasks. It is of limited capacity, and, therefore, the resources within the working memory system will place constraints on the types of tasks that can be undertaken, as well as placing limits on the number and types of tasks that can be carried out concurrently.

1.3 Theories of Working Memory

There are various conceptualisations of working memory, including but not limited to Baddeley's Multi-Component Model (1986, 2001); the Embedded-Processes Model (Cowan, 1999) and Engle, Kane and Tuholski's Fluid Intelligence Model (1999). All have a slightly different focus. In general, there is agreement between all of them that capacity is in some way limited, and therefore only a certain amount of information can be held and manipulated. These three models will be summarised and compared to give context to why Baddeley's model has been selected as the framework for this thesis. Baddeley's Working Memory Model (1986) proposes that working memory consists of four modules: the phonological loop; the visuo-spatial sketchpad; the central executive and the episodic buffer. These are described in detail in section 1.4 below. Baddeley emphasizes the importance of separate components for processing and storing different types of information in working memory, as well as the central executive's role in controlling attention and manipulating information.

Engle, Kane and Tuholski (1999) proposed a 'fluid intelligence' theory of working memory. This framework proposes that working memory consistent of two major components: storage capacity and attentional control. While the storage capacity is similar to that described above (phonological loop and visuospatial sketchpad holding information in a passive state), there is an attentional control component responsible for controlling access and manipulation of information in working memory. Both the storage component and attention control demonstrate limited capacity and therefore complex or prolonged tasks can result in reduced performance as attentional control fatigues (Engle et al., 1999). This model emphasises the effect of individual difference in terms of attentional control, which impacts working memory outcomes (Miyake & Shah, 1999).

With a similar focus Cowan's (1999) embedded-processes model also emphasises the role of attention in working memory. In summary, Cowan proposes that working memory consists of a central focus of attention that can hold a small amount of information, surrounded by a more extensive set of activated representations that can be accessed if needed. Sensory information enters from the environment and passes briefly through a 'sensory store' (not differentiated into phonological/visuo-spatial) and the focus of attention activates features in long-term memory corresponding to the sensory properties of the incoming information and its coding. Attention fatigues and habituates so features remain in awareness but not as focus of attention unless there is a change in state which would then reorient attention. A central executive allows voluntary attentional focus. The (limited) number of items that are attended to then can be linked and form a new, or strengthen an old, representation in the long-term memory. Therefore, both old and novel information is retained in an accessible state, allowing manipulation and problem solving of tasks. Evidence for this comes from the decay of activated long-term memory over time (if distractors are used in a recall task) and the limit to attention in terms of number of items (Miyake & Shah, 1999).

Cowan describes attention as the enhancement of processing information and excluding other information; and awareness as the ability to be aware of the information. Attention can be involuntary (e.g., response to a fire alarm) or voluntary, (e.g., an effortful process of remembering something specific). Encoding of a stimulus is the 'storage' of a set of features that make it more familiar and enhance representation. This encoding can be abstract (e.g., phonological or sematic codes) or sensory (e.g., shape, colour, tone, texture or smell). The focus of attention therefore enhances encoding. Unlike Baddeley's model, this model accounts for different input beyond phonological or visuo-spatial and rehearsal may be used to maintain activation but also recirculation. While the activated memory items decay quickly, long term memory representations remain longer so these can be retrieved after deactivation.

A main difference in comparing Baddeley and Cowan's models is to do with the terms of capacity – in modular theories, each module has its own capacity. While one area might be full, other modules can still 'take over'. Individual difference may occur from differences in capacity between these modules. In Cowan's it is attention overall that will limit working memory capacity, both its processing and storage capacity (by the level of activation and focus of attention).

While it does not discuss different component modules, there is overlap in the embedded processes and WMM in that a central executive appears to be involved to direct resources, and also that items with similar features interfere more with each other than those with different features. The focus of attention may be compared to the episodic buffer of Baddeley's model. This can account for when priority is given for recall of specific items in a list (instead of the list overall) as attention is given to those higher priority (Miyake & Shah, 1999).

Baddeley's working memory model is an influential model and particularly pertinent when studying language development, as it provides a clearly organised system of interacting components. It provides a strong theoretical framework for experimental studies, which is why it has been chosen as the key model for this thesis. The model involves four components that work together: the central executive, which focuses, divides, and switches attention, in order to direct resources within the system appropriately. Two passive storage systems (phonological loop and the visuo-spatial sketchpad) and the episodic buffer, which seems to link WM to long term knowledge.

This compartmentalised model also offers an explanation for heterogeneity in DLD – individual difference may result in different strengths and weaknesses within the different components, which can explain breakdown in memory and language ability at different points (e.g., the difference in verbal and visuo-spatial memory). Verbal stimuli has a special quality in that it can be rehearsed and repeated both externally or internally, and these phonological processes seem key for language and word learning – repeating a word to identify the phonological features while a representation is stored in the long-term memory. For these reasons, Baddeley's working memory model is used to structure this thesis.

1.4 The Working Memory Model

The latest version of the working memory model (Baddeley, 2010) encompasses four main components:

- The Central Executive. This is the overall attentional controller for the WM system and it focuses, divides and switches attention in order to direct resources where they are needed (Henry & Botting, 2017). The processes associated with this component are often thought to involve 'executive functions' (Messer et al., 2019).
- The Phonological Loop. This is a passive temporary storage system for verbal/auditory information that lasts for around two seconds. It is possible to keep information active in the phonological loop by mentally 'rehearsing' using an articulatory rehearsal mechanism (See Figure 1.1)

- Visuo-spatial Sketchpad. This is a passive temporary storage system for visual, spatial and possibly kinaesthetic information. It is possible to keep information active in the visuo-spatial sketchpad by mentally 'rehearsing'.
- Episodic Buffer. This is a multi-modal storage system that links the rest of the working memory components to all information stored in long-term memory. By integrating information from all components, it provides the sense of a 'coherent' experience, and this system may also provide some extra multi-modal storage capacity.

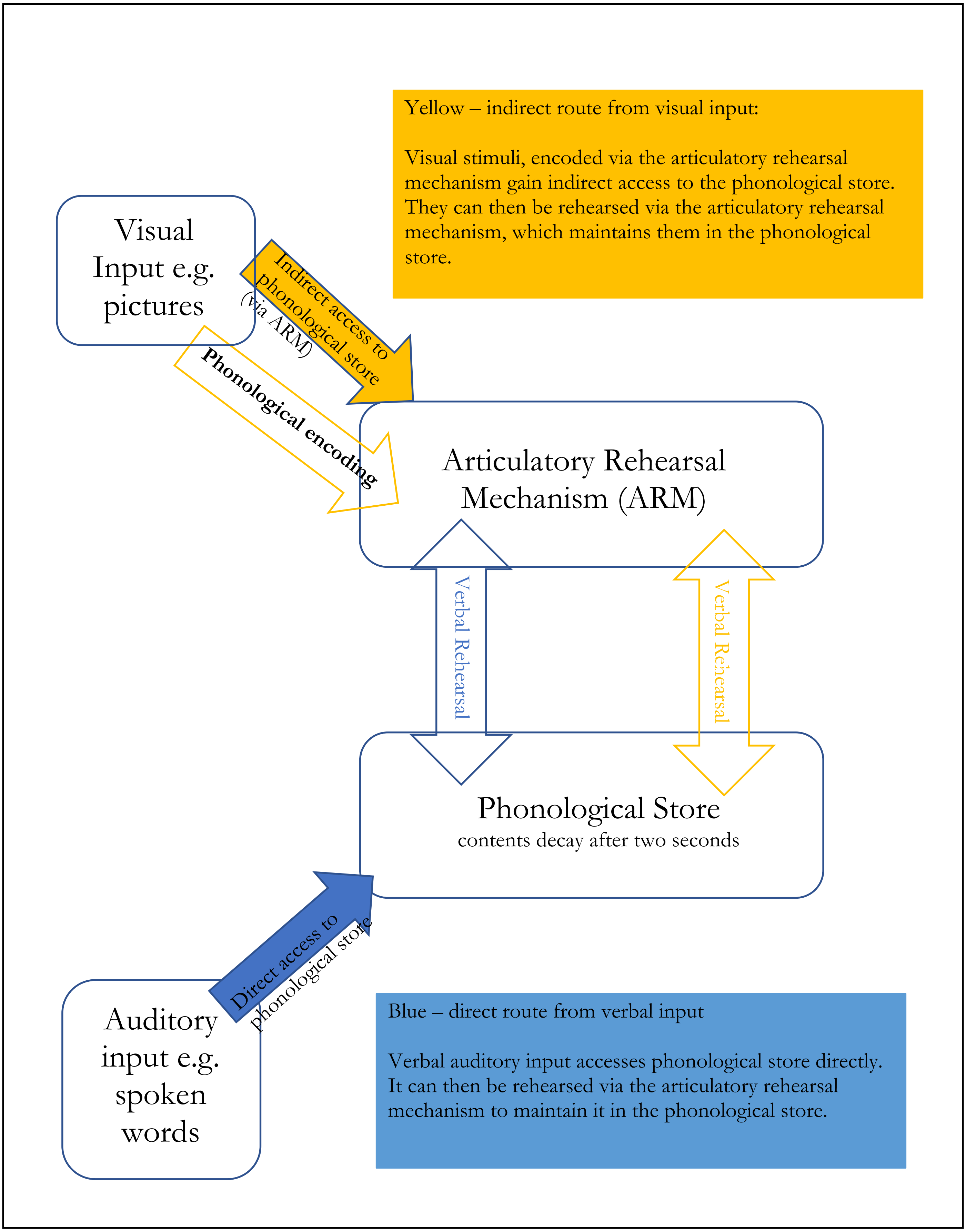
1.4.1 The Phonological Loop

Of particular relevance to this thesis is the phonological loop, a specialised storage system for speech, or speech-like, material. It is potentially key to word learning (Archibald et al., 2006; Archibald & Harder Griebeling, 2016; Clegg & Joffe, 2017; Henry & Botting, 2017; Lum, Ullman, & Conti-Ramsden, 2015) as it allows verbal information to be stored temporarily while representations are formed or 'encoded'. Its use has been evidenced from as early as 18 months (Mani & Plunkett, 2011), and tasks that assess the phonological loop are usually described as measuring phonological short-term memory (PSTM).

The phonological loop comprises a phonological store and an articulatory rehearsal mechanism. The phonological store is the area of the system in which speech material is held, but information here is time-limited and the memory trace decays rapidly within one to two seconds (Baddeley, 2010). The articulatory rehearsal mechanism allows the information in the phonological store to be repeated internally or rehearsed, which counteracts the rapid decay and allows it to re-enter the phonological store and, hence, remain active. Although verbal rehearsal does not always involve overt/spoken speech, it appears to use the same mechanisms – i.e., it happens in real time as words are 'said' in one's head.

The phonological loop is of interest because of its key role in phonological encoding. The two elements of the phonological loop (the phonological store and the articulatory rehearsal mechanism) are important to differentiate due to the difference in how input 'accesses' the phonological store. While auditory stimuli can enter the phonological store directly, visual stimuli must be first translated into a phonological code via the articulatory rehearsal mechanism before they can enter (Baddeley, Lewis, & Vallar, 1984; Henry, 1991a) (Figure 1.1).

Figure 1.1 *The Routes of access to the phonological store via auditory or visual stimuli*



Consequently, for visually presented items (e.g. pictures of easily named objects) to be rehearsed using the articulatory rehearsal mechanism, there needs to be a process whereby the visual items are 'translated' into a phonological code or representation, which can then be rehearsed (see yellow route of Figure 1.1). This 'translation' process is often referred to as phonological encoding, although in some literature it is known as phonological recoding or phonological coding.

To avoid confusion between these many terms, 'phonological encoding' will be used throughout this thesis to refer to the specific process of producing verbal labels for visually presented material – in this case pictures – via the articulatory rehearsal mechanism (Henry, 2011). Note that once phonological encoding has produced a phonological representation, the material can then be stored in the phonological store component of the phonological loop. This is an 'indirect' method of entry to the phonological store (yellow on Figure 1.1) and can be contrasted with a 'direct' method of entry to the phonological store for heard speech material (marked blue on).

A simple example of phonological encoding is when a child names a visually presented object or picture. A more complex example is when a child reads out loud a printed word, or when she silently reads a word. Thus, there are various forms of phonological encoding which can take place for different types of nameable materials. Both types of representations are stored in the phonological store in the same manner and are hypothesized to have similar properties, according to the working memory model (Baddeley, 1986). While the concept of phonological encoding arose from the working memory model, it has broader implications, for example with word production and reading. This thesis is concerned predominantly with its function in working memory but see section 4.3 for discussion of phonological encoding in reading.

There are further distinctions to be made about using the articulatory rehearsal mechanism for phonological encoding. First, phonological encoding refers simply to the derivation of a phonological code for visually presented material (i.e., translation of pictured object to a phonological 'label'.). Secondly, once a phonological representation has been created, it is possible also to use the articulatory rehearsal mechanism to verbally rehearse this representation to keep it active in the phonological loop (which decays within two seconds).

Therefore, in order to verbally rehearse visually presented materials such as pictures in short-term memory task, two steps are required: 1) phonological encoding of the picture names; and 2) subsequent verbal rehearsal of those names. Note that the articulatory rehearsal mechanism carries out both functions, and, importantly, a child could do the first step without doing the second.

The term phonological encoding will be used to refer to the translation process, and the term verbal rehearsal to refer to the additional strategy of reciting picture names in sequence to keep them active. Both phonological encoding and rehearsal can be done overtly (using spoken language that can be heard) or covertly (using internal language that cannot be heard) or partially covertly (using whispering or muttering that can partially be heard). The distinction between these will be made clear, where relevant in this thesis, by referring to covert, partially covert or overt phonological encoding and/or verbal rehearsal.

However, as this process may occur internally, or without obviously interpretable external signs, it can be challenging to investigate or measure what is happening. Some experimental approaches to investigating this area have included neuroimaging or electromyography (Betts, Binsted, & Jorgensen, 2006) and self-reporting (Alderson-Day & Fernyhough, 2015) as well as laboratory experiments such as observing private speech on various tasks (Lidstone et al., 2010).

However, a more direct method of assessing phonological encoding is by using phenomena such as the phonological similarity effect (PSE) or word length effect (WLE), or through investigating the impact of articulatory suppression on these effects (Botting, Psarou, Caplin, & Nevin, 2013; Henry, 2008).

The following sections will explain how these phenomena (PSE, WLE and articulatory suppression) can be used to investigate phonological encoding, and how findings from these tests can be analysed to consider the development of phonological encoding in typically developing children. This will lead to a discussion as to why the PSE has been selected as the key method of investigating phonological encoding in children with DLD for this thesis.

1.4.1.1 The Phonological Similarity Effect (PSE)

The phonological similarity effect (PSE) describes how it is harder to recall, in serial order short-term memory tasks, words that sound similar than those that sound dissimilar. It was originally demonstrated with letters that sounded the same e.g. 'b, d, e, g, v' compared to 'a, x, t, s, h' (Conrad & Hull, 1964). The PSE was later demonstrated with 'rhyming' words (Baddeley, 1966), specifically, how words with the same vowel sound – rather than necessarily requiring a full rhyme, e.g. 'cat, van, lamp' – can also become confused in serial order recall (Nimmo & Roodenrys, 2005). This phonological confusion probably stems from the nature of the "sound storage" in the phonological store, causing lack of distinctiveness between items. For auditorily presented items there is direct access to the phonological store because phonological codes have already been produced during auditory input (see Figure 1.1 – blue direct route). Visually presented items, such as nameable pictures, can only enter the phonological store indirectly after a phonological code has been created; this is achieved by phonologically encoding visual material into a phonological code (Figure 1.1 – yellow indirect route). The PSE could occur due to confusion between items within the phonological store, or perhaps from confusion at the redintegration (reconstruction of items prior to recall) or recall stage (Baddeley, 2007; Cowan, Saults, Winterowd, & Sherk, 1991; Hasselhorn & Grube, 2003).

According to the working memory model, the effect of the PSE is observed even when the short-term memory task requiring recall is entirely non-verbal, i.e., both presentation and recall are done visually / spatially, via presentation of nameable pictures and pointing to the pictures in serial order at recall. This is because phonological encoding (via the articulatory rehearsal mechanism) is triggered or, indeed, 'chosen as a strategy' internally (Henry, Messer, Luger-Klein, et al., 2012). Observing a phonological similarity effect from visually presented stimuli suggests that some phonological encoding into the verbal domain has, therefore, occurred. This phenomenon is a powerful way of allowing us to tap into individuals' use of phonological encoding as a form of verbal mediation and enables us to understand how and when the process develops.

1.4.1.2 The Word Length Effect

Due to the rapid decay of verbal material within the phonological loop, articulatory rehearsal via speech output mechanisms (the articulatory rehearsal mechanism) is used to maintain representations. This rehearsal is thought to occur in real time, and the speed of rehearsal is, therefore, determined by the speaker's rate of overt articulation. The faster the articulation (or speech) rate, the faster the rate of rehearsal and so more information can be recalled (Baddeley et al., 1984). In the same vein, shorter words in terms of syllabic or spoken length are more easily recalled as they are quicker to rehearse than longer words which take longer to articulate. This occurs for both verbal input and visual input, provided that the visual input is translated via phonological encoding (described above) in order to gain entry into the phonological store. As a result of the real time articulatory rehearsal mechanism, the word length effect (WLE) can be defined as the tendency for long words to be more difficult to recall in serial order short-term memory tasks than short words (Henry, Turner, Smith, & Leather, 2000).

The observation of a WLE (where a child is better at recalling in serial order a list of short words than long words) can, therefore, be used as evidence of phonological encoding and/or verbal rehearsal. If recall were not utilizing the articulatory rehearsal mechanism in real time, it would be expected there would be no difference between words of different lengths. The lack of WLE has been found often in children under five years (Henry, 1994), suggesting that phonological encoding may not occur until later in childhood.

1.4.1.3 Articulatory Suppression

Articulatory suppression is a method of blocking the use of the articulatory rehearsal mechanism. As described above, for visual material to access the phonological store, it must be phonologically encoded via the articulatory rehearsal mechanism into a verbal code (e.g., verbal labels for nameable pictures). If the articulatory rehearsal mechanism is already occupied, for example with producing a separate motor plan for 'irrelevant' words to be spoken, phonological encoding cannot occur. Equally, to maintain a verbal representation in the phonological loop for longer than two seconds, it must be rehearsed using the articulatory rehearsal mechanism, and again, if the articulatory mechanism is being utilized by repeating an irrelevant word over and over, the rehearsal of 'to be remembered' information cannot occur. In short: phonological encoding is prevented, and verbal rehearsal is prevented, if the articulatory rehearsal mechanism is being used for another task.

Articulatory suppression experiments, therefore, investigate the 'blocking' of the articulatory rehearsal mechanism during potential phonological encoding or verbal rehearsal, through having participants repeat an irrelevant word over and over at the same time as they are given material to be remembered. Assuming the articulatory rehearsal mechanism will be occupied with this requirement, phonological encoding will be disrupted when information is presented visually, because phonological encoding is prevented (Baddeley et al., 1984). If stimuli are presented auditorily, they can still access the phonological store (see Figure 1.1 - blue direct route), thus the impact of phonological similarity (i.e., a PSE) would remain.

With regard to the WLE, when articulatory suppression is utilised, there is no WLE observed in serial order short-term memory tasks, regardless of the modality of stimuli input. Both visual and verbal input results in the same level of recall for both long and short words when participants must repeat a word out loud throughout presentation and recall of stimulus lists. This is because the WLE occurs due to the use of verbal rehearsal via the articulatory rehearsal mechanism - and this mechanism has been blocked by articulatory suppression. As no verbal rehearsal can take place when the articulatory rehearsal mechanism is occupied, there is no resulting WLE (Baddeley et al., 1984).

Articulatory suppression only impacts the presence or absence of a PSE when the presentation of to-be-remembered material is visual. If visual stimuli are presented, no phonological encoding can occur as the articulatory rehearsal mechanism is occupied with carrying out the distractor task. Hence, no phonological storage is possible. This means that no phonological similarities between stored items will be detected and, thus, phonological similarity has no impact on recall. However, if the method involves verbal presentation of memory items, the PSE is expected to remain, because the material can be stored in the phonological store. As the current aim is to look directly at the process of phonological encoding, the method adopted will utilise ***visual presentation*** of the to-be-recalled material, with, additionally, a non-verbal recall method. This isolates the use of phonological encoding as only children who use it should show the PSE.

1.5 The Development of Phonological Encoding in Children with Typically Developing Language

Conrad, in what is the earliest study on this topic, found that children developed what he termed "speech" coding by the mental age of 5–6 years: that is, by this age they used a phonological encoding strategy to remember lists of nameable pictures, hence becoming sensitive to phonological similarity (Conrad, 1971). Unless prevented by articulatory suppression, by age seven phonological encoding is used to recall visually presented nameable stimuli (Hasselhorn & Grube, 2003), but is generally not thought to be consistently carried out by children younger than 7 (Baddeley et al., 1984; Henry et al., 2000; Palmer, 2000b). There appears to be a qualitative shift toward the use of phonological encoding at 6-7 years (Baddeley, Gathercole, & Papagno, 1998; Gathercole, 1998; Gathercole, Adams, & Hitch, 1994; Henry, 1991a).

The articulatory rehearsal mechanism occurs in real time; therefore, it is thought that an increase in speech rate results in faster rehearsal and, therefore, better recall (Baddeley & Hitch, 1974). There is a linear relationship between memory span and speech rate, as measured by participants' ability to repeat groups of words as fast as possible. Overall, performance on phonological short-term memory tasks tends to be better in children with faster rates of speech (Baddeley, 1986). Rehearsal is more consolidated with a faster speech rate and explains correlations between speech rate and memory span. Those with a greater ability to rehearse words quickly are able to refresh more words in the same time period. Due to this link to speech rate, it has been posited that the developmental increase in memory span observed with increasing age is due to increased speech rate. Children aged 4-11 have been shown to demonstrate word length effects (Henry & Millar, 1991) although this appears to be affected by presentation modality. In addition, it has been shown that adults with a lower memory span demonstrate smaller WLEs (Logie, Della Sala, Laiacona, Chalmers, & Wynn, 1996). This could be due to the type of rehearsal used to recall the lists. Those with a lower span may use naming more than cumulative rehearsal strategies, but this could also explain the absence of WLE in younger children with shorter memory spans. It should not be assumed that the lack of WLE is due to inability to phonologically encode, as it could be due to a reliance on an alternative memory strategy for recall which does not emphasis the WLE.

It should be noted that controversy surrounds the use of WLE as evidence for time-based decay in the short-term memory. Words carry characteristics other than articulation rate which impacts their recall – for example, their familiarity, or the duration of production (which may vary not just in length of the word – 'saloon' for example, has a longer duration than 'hopper' although both words have two syllables due to the longer vowel) (Lewandowsky & Oberauer, 2009). The impact of speech rate and length of words has less impact. As a result, the cognitive processes responsible for the development of WLE and rehearsal/output are unclear. Although the evidence suggests WLEs are observed from 7-9 years, this is more open to inconsistencies than that of PSE, the evidence for which is extremely robust and has been replicated widely (Logie et al., 1996). It is correlated with the use of phonological encoding when it is administered as a purely non-verbal task. Due to the assumed structure of the phonological loop in working memory, PSE is a more appropriate measure of this ability and will be the focus of the method in this thesis. Speech rate and its correlation to memory span will be investigated and discussed separately (see section 4.2).

PSE, compared to WLE, has been more consistently observed and reported (Logie et al., 1996). Findings suggest that at a younger chronological age than 6-7 years, children do not seem to demonstrate the PSE in short-term serial recall tasks - unless the pictures are labelled by the experimenter, which allows direct access of this auditory input to the phonological store (Hitch, Halliday, Schaafstal, & Schraagen, 1988; Hitch & McAuley, 1991) removing the need for phonological encoding. Henry, Messer, Luger-Klein, et al. (2012) found evidence for a PSE in children over 5 years using a non-verbal method where neither the child nor the experimenter produced the words verbally. This ensured that children were using phonological encoding to access the phonological store rather than accessing it directly from existing speech input (i.e., the children were shown short lists of pictures one at a time, and then asked to recall the pictures in serial order by pointing at a matrix of all the pictures). A similar method will be used in the current thesis, whereby any possible verbal input (either at presentation of items or during recall of the list) is carefully prevented by using non-verbal methods.

Jarrold and colleagues suggested a somewhat different interpretation of the emergence of the PSE (Jarrold et al., 2008; Jarrold & Citroën, 2012; Jarrold & Hall, 2013; Jarrold et al., 2015; Tam et al., 2010). These authors have argued against phonological encoding changing qualitatively with age and that children use other strategies (possibly visual strategies or no particular memory strategy, e.g. Palmer (2000b)) until phonological encoding is 'switched on' at age 6-7 years. Instead, they propose that phonological encoding is present in all younger children, but inconsistent and difficult to measure before 6-7 years. This argument does tie in with the fact that some studies *have* found a PSE in younger children (Al-Namlah et al., 2006; Jarrold & Citroën, 2012; Tam, Jarrold, Baddeley, & Sabatos-DeVito, 2010).

However, all the studies that have found a PSE in younger children used the same method – visual presentation, but requiring verbal recall: children were shown pictures, initially asked to verbally name them all, then showed the pictures one at a time and immediately asked to recall verbally the pictures they had seen in serial order. This effects phonological encoding, as children are required to form a speech output plan to recall the list of items, and this might very well involve using the articulatory rehearsal mechanism (Henry, 1991). As a result, this preparation of a verbal output plan could explain the PSE observed in younger children such as 6-year-olds.

Another key point is that Jarrold and colleagues suggest that a PSE has not been *consistently* detected in younger children due to methodological issues around scaling: the effect of low levels of memory span resulting in the PSE being too small to detect. For example, if a child has a span of only two pictures, when recalling such a short 'list' it is hard to see whether a difference between recall of phonological similar and dissimilar items due to phonological similarity emerges (Jarrold & Hall, 2013). As children get older, their memory span increases, thus allowing more scope to reveal a PSE reflecting a difference between somewhat longer similar and dissimilar lists. It is possible that a low memory span makes the PSE is difficult to detect (Jarrold, Danielsson, & Wang, 2015), or that the limited span could prevent the use of phonological encoding and therefore PSE from being observed (Jarrold & Hall, 2013). Nevertheless, there are several examples of studies in the literature where despite low span levels, children have demonstrated the PSE (e.g., Henry, 2008).

Further, at least some of the arguments made by Jarrold and colleagues may confound phonological encoding and verbal rehearsal. In particular, if verbal output has been required for a serial short-term memory task (e.g., remembering lists of pictures verbally), some authors would argue that the preparation of a speech output plan to recall the list is very like a 'single' full rehearsal (e.g. Cowan et al., 1992; Henry, 1991b). In other words, it is possible that verbal recall triggers the articulatory rehearsal mechanism and results in the observed PSE. Hence, because many of the previous studies have used verbal output methods, they do not provide a true test of phonological encoding without any potential confounding effects.

In this case, regardless of whether phonological encoding has taken place, it is not evidence of verbal rehearsal, or any other maintenance strategy, being used. Phonological encoding, as evidenced by the PSE, simply reflects the translation process of visual input to a verbal code and does not imply verbal rehearsal. It is phonological encoding that is the main area of investigation in the current thesis. However, the appearance and increased efficacy of verbal rehearsal in working memory is another factor that is likely to be linked to the age-related improvement in short-term memory performance. This will be treated as a separate subsidiary issue in the current thesis and covered in the second research question. The type of verbal rehearsal strategy utilized – Naming, Complete or Cumulative rehearsal – and the development of this ability will be discussed in section 3.3.1.

1.6 Summary of Chapter 1

Phonological encoding is the translation of visual stimuli (such as pictures of nameable objects) into a verbal (phonological) code by way of the articulatory rehearsal mechanism – for storage in the specialized speech-based phonological store. This newly converted phonological information may or may not then be continuously repeated via the articulatory rehearsal mechanism (i.e., verbally rehearsed), in order to keep this information active and support recall. Evidence from studies on the development of the PSE suggests that phonological encoding is consistently in use by children with typically developing language from around age 6-7 years, with PSE observed in children older than 6-7 years, but small or no PSE observed in children under 6 years.

As it is widely evidenced that children with DLD have impaired working memory in terms of several components of the working memory model, it seems likely that their phonological encoding will be impacted. The aim of this thesis is to explore whether this is observed in children with DLD through direct investigation of the PSE, looking at how the development of the PSE proceeds in this group, and whether phonological encoding and its development differs compared to children with typical language between 6 and 10 years. The next chapter will explore what is known to date about phonological encoding, the PSE and verbal strategy use in children with DLD.

CHAPTER 2

Developmental Language Disorder

Having considered what phonological encoding is, how it can support working memory and how it develops in typically developing children, it's clear that phonological encoding is crucially connected to language development. Due to this close association, phonological encoding and related processes are likely to be impaired in children who have Developmental Language Disorder (DLD). This chapter will explore the research into DLD and associations with components of the working memory model, including the central executive, visuo-spatial short-term memory, and the phonological loop, before focussing specifically on phonological encoding and identifying gaps in the research that this thesis aims to address, including the introduction of the research questions to be addressed.

2.1 What is Developmental Language Disorder?

Developmental Language Disorder (DLD) is the term used to refer to children and young people with a specific type of language difficulty. DLD is a persistent neurodevelopmental disorder, unexplained by any other syndrome or difficulty, with a primary difficulty with verbal skills (McGregor, 2020). Formerly, many of these children were usually referred to as having Specific Language Impairment (SLI). Recent work has resulted in a change in both the name and diagnosis criteria of this disorder. In brief, SLI referred to children whose language does not follow the typical course of development despite typical development in other areas (Bishop, Snowling et al., 2016a). This typical development in other areas assumed normal non-verbal abilities (i.e. a non-verbal IQ of 85 or more), and, as a result, a discrepancy between verbal and non-verbal ability in children with the condition (Reilly et al., 2014). A main difference between 'SLI' and 'DLD' is there is no longer a requirement for a discrepancy between verbal and non-verbal IQ, nor a minimum level of 85 for non-verbal IQ (Leonard, 2020).

Children with SLI/DLD fail to make adequate progress in language development (phonology, vocabulary, grammar, morphology) despite the absence of underlying intellectual, neurological, social or emotional impairment (Reilly, Tomblin, et al., 2014). The prevalence of DLD is estimated at around 7%, rising to 11% if children with low-average non-verbal IQ/co-morbid conditions are included (Norbury et al., 2016; Tomblin et al., 1997) and the disorder has a great impact on academic, social, emotional and professional achievement (Conti-Ramsden et al., 2019; Dubois et al., 2020).

2.2 Developmental Language Disorder and Working Memory

The working memory model provides context for research and allows analysis of the development of working memory. Understanding this process of development is crucial in order to help children maximise their intellectual progress (Diamond & Lee, 2011). This is useful when considering DLD and differences in working memory development compared to the TD population, and the framework introduced in section 1.4 will be used to do so here.

Three clinical markers are often used for identifying cases of DLD, and two of these in particular involve working memory integrally: sentence recall and non-word repetition (Paul, 2020). Working memory is specifically implicated in difficulties with language: children with DLD are eight times more likely to have working memory difficulties than peers with typically developing language across all components of the working memory model (Vugs, Hendriks, Cuperus, & Verhoeven, 2014), which in turn is thought to impact on other aspects of memory also (Jackson et al., 2020). While for some time working memory difficulties were cited as potential cause of DLD, evidence now shows that while not all children with DLD have working memory problems, the majority show some difficulties and these contribute to language learning difficulties (Archibald & Joanisse, 2009). These significant difficulties include, for example, reduced phonological short-term and working memory when compared to age matched peers (Archibald & Joanisse, 2009; Lum, Conti-Ramsden, Page, & Ullman, 2012); poorer narrative recall compared to both age and language matched peers (Dodwell & Bavin, 2008); and poorer word recall compared to age matched peers (Ellis Weismer, Evans, & Hesketh, 1999) - for review, see (Henry & Botting, 2017). Montgomery, Gillam, and Evans (2016) report that children with DLD present with a marked deficit in simple verbal working memory storage (as tested by non-word repetition, digit span and word span) compared to age matched peers.

In particular, phonological short-term memory is closely related to new word learning in children (Gathercole et al., 2005; Mosse & Jarrold, 2008) and it has been argued that poor phonological short-term memory is a root cause of language difficulties in the first place (Baddeley et al., 1998; Jarrold, Baddeley, Hewes, Leeke, & Phillips, 2004). Children with good phonological memory have greater vocabulary knowledge than children with poor phonological memory (Gathercole & Adams, 1993; Michas & Henry, 1994), and this effect remains at 5 and 13 years (Gathercole et al., 1999). It is therefore unsurprising that working memory also predicts receptive language abilities. This relationship may not be causal, but it appears important – words must be held in one's head for fast mapping, which could explain the key link to expressive language. This deficit likely impacts on new word learning - children hearing a new word must first perceive and encode the sequence and then be able to hold the sequence in a temporary memory store with a robust enough representation to support further processing, articulation, and connection to meaning (Graf Estes, Evans, & Else-Quest, 2007).

Children with SLI/DLD have a deficit of phonological short-term memory of 1.27 standard deviations below their peers with typically developing language, according to a meta-analysis of relevant findings (Graf Estes et al., 2007). Children with SLI/DLD tend to do poorly relative to children with typical language on short-term memory tasks (Ellis Weismer et al., 1999;

Gathercole & Baddeley, 1990; Gillam, Cowan, & Day, 1995) and this may include visuo-spatial short-term memory as well as phonological.

This wealth of literature leaves no doubt that working memory is consistently affected in children and adults with DLD, but the process of disruption and where exactly difficulties lie is still not fully clear, particularly beyond the phonological loop. The following sections will consider the different modules of the working memory model and what is known about how they appear to be impacted in children with DLD in order to identify particular areas of concern.

2.2.1 Working Memory and DLD: The Central Executive

There is some limited evidence that children with DLD have a poorer Central Executive function, on both verbal (Ellis Weismer et al., 1999) and non-verbal (Alloway & Archibald, 2008; Archibald et al., 2006) tasks. Children with SLI/DLD have difficulty with complex memory span tasks beyond the difficulties of simple phonological storage tasks (Vugs, Hendriks, Cuperus, Knoors, & Verhoeven, 2017), suggesting difficulties at the higher level of central executive rather than restrictions to the phonological loop. In addition, significant difficulties have been found in non-verbal central executive tasks in children with SLI/DLD (Im-Bolter, Johnson, & Pascual-Leone, 2006), suggesting these difficulties are not restricted to the language element of these tasks (Henry & Botting, 2017).

However, some caution is needed in the interpretation of these differences. Central executive difficulties could be due to other cognitive difficulties or processing limitations (e.g., input or output), or due to the overall impact of language deficit on completing tasks that require a language load, for example to understand instructions of the task. Most executive tests require a high level of linguistic competence, and this could result in a lower level being obtained than is a 'true' representation (van der Lely & Howard, 1993) The control group were age matched peers rather than language matched which would compare verbal ability more closely. However, Marton (2008) and Henry, Messer, and Nash (2012) also found significantly poorer results by children with SLI/DLD on both verbal and non-verbal central executive tasks compared to typically developing peers on the same tasks, even when non-verbal ability was controlled for. While this could be due to general memory limitations (Gray et al., 2019), it appears that there are difficulties in the central executive, which are beyond simple PSTM in children with DLD.

2.2.2 Working Memory and DLD: Visuo-spatial short-term memory

In addition to central executive difficulties, or perhaps because of a more general working memory difficulty (Montgomery, Magimairaj, & Finney, 2010) visuo-spatial memory is also implicated in DLD. Due to the nature of DLD, most research into the link between this and memory has focused on the verbal, or phonological, aspects of working memory, but there is growing interest about the visuo-spatial domain. Visuo-spatial short-term memory requires the individual to hold in mind and report back spatial or visual information, and is usually tested through recall of location, or sequence patterns.

Vugs et al. (2014) administered the Automated Working Memory Assessment, AWMA, (Alloway, 2007) to a large sample of four-year-olds with SLI/DLD, and chronological age matched controls. The SLI/DLD group performed significantly more poorly on all working memory measures compared to the control group: including the visuo-spatial measures. In contrast, other studies have found performance on visuo-spatial working memory tasks to be comparable in children with SLI/DLD to those of children with typical language. Alloway and Archibald (2008) compared eleven 8-year-olds with SLI/DLD to an age matched group of children with typically developing language but with Developmental Co-ordination Disorder (DCD). Participants completed the AWMA, as above. The children with SLI/DLD demonstrated difficulties with both the phonological short-term memory and phonological working memory tasks, but not with the visuo-spatial tasks of either domain.

Archibald and Gathercole (2006) tested visuo-spatial short-term and working memory in a small sample of children with SLI/DLD and compared their performance to language and age matched peers on the AWMA. They found no difference on performance with age matched peers, and better performance on one measure compared to language matched peers.

Overall, although there is some contrasting evidence, the studies finding no difficulties with visuo-spatial short-term memory have a very small sample size. The weight of evidence with the largest, most robust studies appear to demonstrate an impairment in the visuo-spatial domain in children with DLD when compared to age matched peers at least when younger. Visuo-spatial memory appears to be more important, and differentiated, in language learning earlier on in development, and becomes less relied upon as children grow up (Gray et al., 2019).

This impairment is not as great as the difference between verbal working memory abilities in children with and without DLD, but it does appear that difficulties are not exclusively restricted to the phonological loop. However, further evidence comparing to language matched peers could provide insight into specific difficulties.

2.2.3 Working memory and DLD: The Phonological Loop

Phonological short-term memory (PSTM) and the phonological loop have been extensively investigated in children with DLD. PSTM difficulties in children with DLD are widely accepted (Archibald & Joanisse, 2009; Baddeley et al., 1998; Botting & Conti-Ramsden, 2001; Chiat & Roy, 2007; Durkin & Conti-Ramsden, 2007; Ellis Weismer et al., 1999; Kirchner & Klatzky, 1985; Lum et al., 2012; Montgomery, 1995; Pickering, Gathercole, Hall, & Lloyd, 2001; van der Lely & Howard, 1993). A possible explanation of the difficulties observed with language development in children with DLD is a specific phonological storage deficit hypothesis (Archibald & Gathercole, 2007; Baddeley, 2003; Bishop, North, & Donlan, 1996), leading to much interest in the phonological loop component of working memory.

The phonological storage deficit hypothesis assumes a specific deficit in the temporary storage of novel phonological information. If an individual has a weakness at holding in mind verbal information in the phonological loop, by way of the articulatory rehearsal mechanism whilst accessing the phonological store, it will be harder for the features of the word to be analysed and for phonological representation to be transferred to long-term memory (Brown, Hulme, & Gathercole, 1996; Gathercole, Service, Hitch, Adams, & Martin, 1999). It is possible that the difficulties with phonological short-term memory (PSTM) capacity are responsible for the difficulties with language in SLI/DLD: that the phonological loop is crucial to aid word learning, and therefore a breakdown at this part of the model results in later difficulties with language (Archibald et al., 2006).

Limited phonological short-term memory capacity may adversely affect vocabulary acquisition (Jarrold et al., 2004; Mosse & Jarrold, 2008). In typically developing children, early phonological working memory (at 24-30 months) was the best predictor of later (41-49 month) expressive language – a better predictor even than early expressive language (Marchman & Fernald, 2008), and there is a link between nonword repetition ability and vocabulary levels (Gathercole et al., 1999).

What is known about PSTM in children with DLD has been tested through various tasks such as digit and word span, nonword repetition and word length effects, and this will be explored in the following sections. Understanding of the phonological loop, specifically phonological encoding and PSE presence in children with DLD will then be discussed in more depth.

2.2.3.1 Digit and Word Span

Testing PSTM can be carried out through digit or word span tasks. On digit span tasks, participants must repeat auditorily presented lists of digits. After successful recall at a set list length, an extra digit is added, and this is continued until the participant fails to accurately recall any further digits. The longest list length they recall successfully is classed as their 'digit span'. Word span tasks are the same but require repetition back of lists of words. Standardised assessments of digit or word span include the Working Memory Test Battery for Children (WMTB-C; Pickering & Gathercole, 2001), and on testing with these assessments, children with SLI/DLD have demonstrated lower spans, and therefore poorer phonological short-term memory, than both chronological age and language age matched peers (Archibald et al., 2006; Ellis Weismer et al., 2000; Gillam et al., 1995; Montgomery, 2004). Children with DLD also score significantly more poorly on digit recall tasks compared to both typically developing peers and peers with resolved late talking – suggesting a fundamentally different course of language difficulties compared to the latter (Petruccelli, Bavin, & Bretherton, 2012).

2.2.3.2 Nonword repetition tasks

Further evidence for impaired PSTM functioning in DLD comes from non-word repetition tasks, which test phonological short-term memory. The child hears a word, which would be legal in the test language e.g., 'barrazon' or 'woolgalamic' in English. If a live presentation rather than a recording, the examiner obscures their mouth, to prevent visual cues, and the child must repeat it back. There are standardized assessments available to test this, e.g. the Children's Test of Nonword Repetition (Gathercole & Baddeley, 1996) which includes words of two to five syllables in length. This requires perception, encoding, storage, retrieval, and production for success, as participants must store an unfamiliar sound sequence, and form a motor plan to repeat it back. Children with DLD show a greater difficulty with these tasks than age and non-verbal IQ matched peers with typical language development (Archibald & Gathercole, 2007).

Further, children with DLD have repeatedly been shown to have demonstrated significant difficulty repeating longer nonwords (Petruccelli et al., 2012), reflecting limited phonological short term memory capacity (Gathercole & Baddeley, 1990). This finding supports a phonological memory deficit in DLD, suggesting difficulties in the articulatory rehearsal mechanism. This maintenance is required to rehearse the target word to keep it active in the phonological loop while the motor plan is formed. If PSTM is a key aspect of word learning, allowing new speech sounds to be held in memory while creating stable, long-term phonological representations of words in long term memory (Jarrold, Thorn, & Stephens, 2009), then a disruption of this aspect would be expected to result in a language impairment. In typically developing children, phonological memory appears to continue increasing in capacity until age 14-15 years (Gathercole et al., 2005), but in children with DLD/SLI this development appears to stop by age 11 (Gina Conti-Ramsden & Durkin, 2017).

However, verbal repetition tasks such as the nonword repetition task carry high speech output requirements. This could be challenging for children with language difficulties – i.e., findings of poorer working memory performance of children with DLD could be due to memory limitations and/or a result of poorer articulation and motor skill (Snowling, Chiat, & Hulme, 1991), i.e. the test does not identify whether poor results are due to difficulties holding the new word in working memory or articulating it.

To counter this criticism, Gathercole et al. (1999) designed a nonword repetition task that required a nonverbal response and compared it to the standard verbal recall procedure. In the nonverbal response mode, children had to identify if a sequence of novel non-words was the same or different as the one they had just heard. Children performed similarly on both tasks, suggesting the limitation was phonological memory rather than speech output. In both cases, it is necessary to store the information before recall in the phonological loop. In addition, the results of this study showed a significant relationship between task performance and baseline vocabulary, i.e., children with a bigger vocabulary had a greater phonological memory capacity. This suggested that the difficulty with phonological memory was linked to vocabulary learning, regardless of whether the task had speech output demands.

2.2.3.3 Word Length Effects

The WLE phenomenon has also been used to investigate the phonological loop in children with SLI/DLD. As explained in section 1.3.1.2, the WLE is observed in full recall tasks but not probed recall tasks in children under 7, as the latter does not require rehearsal and so there is no decay effect from the 'real time' speech rate of the articulatory mechanism, but only during verbal recall. Similar results were found for 7-year-old children with SLI/DLD: a WLE observed when full verbal recall was required on a word length effect task, but not when a probed recall protocol was used (Balthazar, 2003). In this study, selection criteria for the language impaired participants were language scores 1.5SD below the mean on two tests of language development, and NVIQ of 85 or more. Two control groups were also tested: one matched for age, and one for language levels of the children with SLI/DLD. None of the groups showed WLE in the probed recall condition, and children with SLI/DLD performed similarly to both age and language matched peers. All groups showed a WLE in the full recall condition, but the SLI/DLD group performed significantly less well than their peers with a smaller WLE. This was comparable with findings in the study by Henry (1991b), comparing children with SLI/DLD to younger children with typical language, with results which suggested that there is a difficulty for children with SLI/DLD with verbal rehearsal and could indicate impairment of the articulatory rehearsal mechanism, as that is required to produce the output in a full recall method, as opposed to simple storage in the phonological store in the probed recall method.

These findings indicate a difference in phonological loop functioning in children with DLD compared to children with typical language, both chronological and language age matched, but there is further evidence that this does not appear to be the only challenge in their working memory, contributing to compelling evidence that phonological short-term memory, and therefore the phonological loop, is compromised in children with DLD. Some suggest that there is a bidirectional relationship between phonological working memory deficits and language difficulties (Bishop, 1994; Montgomery, 2002). A difficulty with processing of phonological working memory would impact language learning, and language learning in turn will impact memory processing (as attentional resources will be diverted into recalling lexical knowledge). It therefore seems highly likely that phonological encoding will be impacted in some capacity in children with DLD.

Children with DLD demonstrate reduced receptive and/or expressive vocabulary (Gina Conti-Ramsden & Jones, 1997; Ellis Weismer et al., 1999; Hick, Joseph, Conti-Ramsden, Serratrice, & Faragher, 2002) as well as weak creation and storage of semantic and/or phonological representations, leading frequently to word-finding difficulties. This means they may not have a phonological representation in their vocabulary for a given word, or they do have a stored representation but it may lack the strong phonological features required for recall (Gillon, 2005; Stackhouse & Wells, 1993). As a result, their ability to encode a visual stimulus into a phonological representation would be impaired. In addition, general processing difficulties would also impact phonological coding: in a study investigating verbal rehearsal in DLD children, participants were provided with free recall lists and instructed to say each label aloud after each item. The DLD group were less able to maintain and regenerate verbal forms in their short-term memory compared to controls. It was concluded this was due to a limited capacity for processing due to the high linguistic demands of the task, and it appears uncertain that this was specifically linked to phonological encoding (Kirchner & Klatzky, 1985).
The difficulties with phonological short-term memory in children with DLD are unequivocal, and the evidence for a more general working memory difficulty is also growing. There is clearly a link between working memory and DLD, leading to questions about inner speech development, and specifically phonological encoding. Little research explores DLD and phonological encoding processes specifically, despite this evidence that PSTM is affected.

The difficulties with phonological short-term memory outlined above suggest there is a high chance that phonological encoding may be deviant or even absent in this population yet, to the author's knowledge, this has not been categorically tested to date. Using the PSE as a marker of the presence or absence of inner speech allows insight into the development of working memory in different populations. Although there is a range of research regarding the development of PSE in children with typically developing language (see section 1.5), there is limited research as to the development of this mechanism in children with DLD, in particular with reference to the articulatory rehearsal mechanism as opposed to the phonological store alone. The next section explores what is known so far about DLD and phonological encoding, a measured through the PSE, and the gaps that this thesis aims to fill.

2.3 DLD and the PSE

Having identified unequivocal findings that working memory is compromised in children with DLD, particularly in the verbal domain, phonological encoding, studied via the phonological similarity effect, becomes of particular interest in understanding what may be compromised in this language atypical population.

Investigation into the presence of the PSE in children with language difficulties has produced mixed conclusions. Three studies found to investigate PSE in children with SLI/DLD will be discussed, with mixed findings regarding the age of development of the PSE in this demographic.

Gathercole and Baddeley (1990) investigated the PSE in a very small sample of six children aged 7 and 8 years, with SLI/DLD, compared to two control groups, one matched for chronological age and one matched for language age. PSE was tested via auditory presentation of phonologically similar/dissimilar words, with non-verbal recall (the participants pointed to the pictures that had been said in order). The task started with two items at a time and increased up to a list length of six words. Overall, children with SLI/DLD demonstrated poorer recall than the control group (i.e., overall smaller memory capacity). PSEs were observed for the SLI/DLD group when recalling lists of four items, but not for five- and six-word lists, where PSE was observed for the two different control groups (i.e., the SLI/DLD group performed similarly poorly at recalling both rhyming and non-rhyming pictures with a list length of five or above).

This task tested verbal rehearsal but not encoding, due to the auditory input allowing direct access to the phonological store. However, the lack of any phonological sensitivity at a higher level suggests that possibly the SLI/DLD group moved to a non-verbal memory strategy and ceased attempting any verbal rehearsal once the task was beyond their capacity. The small sample size means statistical tests had low power to detect differences.

Van der Lely and Howard (1993) repeated this study and found the opposite effect, that children with SLI/DLD did present with a PSE comparable with language age matched peers. They also investigated a small sample of six children with SLI/DLD with a mean age of 7 years, whose language scores were more than 1.5SD below the normal range for their age, and with nonverbal abilities within the normal range for their age (i.e., above 85). The control group consisted of 17 children matched to each individual in the SLI group on three different language assessments, to provide comparable language age matched controls. An examiner read out a list of words (either phonologically similar or dissimilar, counterbalanced for order) starting with a list length of two. After the list was presented (auditorily) the child was provided with a response sheet with pictures on from which they had to point in the same order to the words they had heard. There were four trials at each list length, and if two or more trials were answered correctly, another word would be added to increase list length by 1. The second part of the experiment involved the child repeating the words they had heard (i.e., responding verbally) rather than pointing. All three groups demonstrated a PSE, and there was no different in the effect size between the SLI/DLD group and their language-age matched peers. Children with SLI/DLD did better with pointing recall than verbal repetition recall in terms of span performance. Again, these findings are of limited value because of low statistical power.

Couture and McCauley (2000) carried out an experiment into PSE presence, but in children who only had phonological impairments, so language comprehension ability was in the typical range. The participants were again a small group of children aged six years, and chronological age-matched controls. At this age in typical development, it would be expected to observe a PSE in these sort of recall tasks. The method was as above, with stimulus words (labels of objects) spoken by an examiner, and responses recorded by children pointing to the words they had heard by selecting the picture of that object in serial order. Order of list type (phonologically similar or dissimilar) was counter balanced. The results demonstrated a PSE in both a language impaired group and the control group, comparable with the study above, although the phonologically impaired children did have an overall shorter memory span which was not statistically significant, potentially due to the very small sample size. As with the previous investigations, the sample in this study was small, and the results for phonological similarity did not reach significance. In addition, the children tested had quite different needs from those of children with SLI/DLD with an overall language impairment.

Our information about PSE in children with SLI/DLD is clearly limited by the small number of investigations into this field, and by these investigations having low sample sizes which makes detection of differences more difficult. In addition, none of the previous studies about PSE in DLD/SLI used a full non-verbal presentation and recall method. As a result, none fully explored phonological encoding, which only occurs when visual stimuli are presented, as then access to the phonological store is indirect (see Figure 1.1). Although they provide a suggestion as to verbal rehearsal, the current study aims to provide novel data with more specific information as to the method of phonological encoding in children with DLD.

A consideration in task administration is that overall language abilities can impact performance even on non-verbal tasks, due to the reliance on comprehension for instructions of administering most assessments. In addition, work by Botting (2005) suggests that the relationship between non-verbal IQ and language ability in the DLD population is not constant. When measuring non-verbal abilities of children with SLI/DLD over 7 years (from 7 to 14 years, with testing points at 8 and 11 years), non-verbal IQ dropped an average of 20 points. The process of development was significantly different to that in typically developing peers. Non-verbal IQ requires working memory skills, and it may be these cognitive abilities that are impacted in DLD, as discussed, and the difficulties appear to become more pronounced with age. As a result, considering non-verbal IQ in the control sample is important for a stronger comparison between groups.

2.4 Summary of Chapter 2

As described above, DLD is known to affect many aspects of working memory. In particular, phonological working memory is implicated in many of the difficulties associated with the condition.

The current study focuses on age differences in phonological encoding in children with DLD, who have difficulties with working memory in general, and phonological working memory specifically. In order to study change in phonological encoding, this research recruits a "younger" sub-group (of children with DLD group and a control group of non-verbal IQ and age matched children) aged 6-7 years, the age at which most evidence shows that children (with typical language at least) are using more phonological encoding strategies to recall on short-term memory tasks and the PSE is consistently observed and measurable (Henry, Messer, Luger-Klein, & Crane, 2012).

Findings from these participants will be compared to 'older' groups, aged 9-10 years, of both DLD and typical language controls. Comparing the changes between the younger and older group may shed some light on the development of this strategy. It also avoids a methodological issue of comparing DLD children to TD peers matched for language age. This can confound data as the control group are likely to be chronologically younger, meaning the children with DLD will have different experience and language development opportunities, and as a result the groups are not as matched as they appear (Bishop, 2014). The aim is to answer the following:

- RQ1: Do children with DLD have impairments to phonological encoding compared to age and non-verbal IQ matched typically developing children?

This is the first of three research questions to be addressed in this thesis. The next chapter investigates a wider process also known as 'inner speech' or verbal mediation, specifically that of verbal rehearsal and other strategies known to be used to support working memory.

CHAPTER 3

Inner Speech and strategy use

Section 1.2 discussed how phonological encoding can be used to translate non-verbal information, permitting the rehearsal of non-verbal information (necessary for working memory and in particular word learning), and section 2.3 considered what is known so far about how this process develops in those that do not demonstrate typical language development, namely those with DLD.

Another form of verbal mediation overlaps with phonological encoding: the ability to use internal speech to modulate behaviour during problem solving ('private' or 'inner' speech as described by Vygotsky). Part of this verbal mediation involves verbal rehearsal, thought to be intrinsic to effective verbal working memory (Baddeley, 2010). Both skills (phonological encoding and private/inner speech) appear to be essential during language learning (Al-Namlah, Fernyhough, & Meins, 2006) which is what has led to this investigation of the process in children with atypical language development. This chapter will discuss the development of private speech; how it may be affected in DLD; its role in working memory and specific verbal rehearsal strategies employed during working memory tasks, and the possible impact of DLD on these strategies, focussing on RQ2: Does the development of verbal rehearsal strategies follow the same pattern in children with DLD between 6 and 10 years as their age and non-verbal IQ matched typically developing peers?

3.1 Private or Inner Speech

The experience of an internal monologue, translating what we experience into 'spoken' vocabulary in our heads, is consistently described as involving a verbal element (Baars & Franklin, 2003) in the absence of overt or audible articulation. Unsurprisingly, as it is a uniquely individual experience, and occurs silently and concurrently with other tasks, it is hard to pin down and study objectively. 'Verbal mediation' which can be overt or covert, is sometimes used to describe the same self-regulating monologue (Winsler, 2009).

Young children, notably those in the preschool years, 'talk to themselves', for example when trying to solve a difficult problem. This behaviour was observed by both Piaget and Vygotsky and was incorporated into their more general theories about child development. Piaget first described this behaviour as 'egocentric speech' and believed that limited cognitive abilities meant children were unaware of some of the communication functions of speech with other people. Over time, as children's communicative skills developed, this 'egocentric' speech was replaced with mature social speech (Piaget, 1962).

Vygotsky (1934) interpreted the development (and eventual disappearance) of this self-talk differently. Vygotsky believed that 'private speech', which involves similar behaviours to egocentric speech, supported cognitive problem-solving, and developed gradually through childhood. He also believed that this private speech, when the child talks to themselves to guide their thinking, gradually became internalized. In contrast to Piaget, Vygotsky believed the child was appropriating language from its social function for the self to support internal thinking and problem solving. Vygotsky supposed that eventually this created verbally mediated thought (Winsler, 2009) which became internal 'inner speech'.

Researchers coming from this Vygotskian developmental perspective also have used the term 'private speech' to describe overt speech which is specifically to or for oneself, as contrasted with social speech which is for use with interaction with others (Winsler, 2009). According to this perspective, private speech progresses into partially covert speech which may include muttering, whispers, mouthing of words, or other incomprehensible verbalisations, and still later at around seven years of age, fully covert inner speech is believed to be present when there is no visible sign of spoken language (Winsler & Naglieri, 2003). Other analogous terms used variously in the literature for egocentric and private speech include 'self-talk', 'self-regulatory speech' or 'self-directed speech' (Lidstone, Meins, & Fernyhough, 2010).

Al-Namlah et al. (2006) observed private speech alongside phonological encoding on various executive function tasks in a sample of 8-year-olds. The memory task involved the children being shown pictures of high frequency words that were either phonologically similar or dissimilar. They had to recall, verbally, as many as possible in serial order. The executive function task was a standard Tower of London task (where children must recreate a pattern of blocks in as few moves as possible). The researchers found that children who used private speech performed the tasks better, suggesting this mediation supported cognitive performance. In addition, there was a correlation between use of private speech and presence of phonological encoding, with private speech becoming more internalized at the same time as the PSE appeared, suggesting a maturation of domain-general self-regulation and use of phonological encoding within working memory. This is in line with Vygotsky's theory that internalization occurs with language development becoming more advanced.

Studies by Landry, Smith, Miller-Loncar, and Swank (1997) in samples of typically developing children showed that facilitative language from mothers at age three predicted better executive function and use of private speech at age six. Berk and Spuhl (1995) found that typically developing children who were permitted by their parents to talk to themselves and solve problems independently had children with more effective private speech.

In the current thesis, 'private speech' will refer to the use of overt verbalisations for self-regulation during cognitive tasks. When private speech becomes fully internalized it will be known as 'inner speech' - a similar self-regulatory monologue, but not verbalized. Therefore, the term ‘inner speech’ will be used to refer to covert processes which involve language-based thought, including verbal rehearsal. These terms will be used as distinct from ‘phonological encoding’, which in the current thesis refers to a specific process within the phonological loop component of the working memory model.

3.2 Private speech and DLD

Children with DLD do not develop language as expected at the same rate as their peers, and their reduced receptive language means they may not benefit from the verbal input provided by caregivers in the same way as their peers, e.g., if they cannot understand the vocabulary being used. As a result, it would be expected that their own private speech will be delayed in development. Winsler, Diaz, and Montero (1997) trialled problem-solving tasks in typically developing children preceded with or without scaffolding and found children who were observed to produce more private speech did better on subsequent trials. These studies describe the importance of private speech to language development and executive function in general. This could result in a permanent deficit to the private speech of children with DLD. If there is a link in cognitive development that results in a shift in verbal mediation, and therefore phonological encoding, to internalization, it would be expected this would also be delayed.

There are some examples of studies comparing use of private and inner speech in children with DLD in relation to typically developing peers, although there is inconsistency in the findings. Abdul Aziz, Fletcher, and Bayliss (2017) investigated the use of private speech in a large sample of children aged 4-7 years with SLI/DLD and compared them with typically developing controls. The participants carried out the Tower of London task. It was suggested they could talk to help them by the examiner saying ‘some children like to talk when playing this game. If you want to talk, it’s fine.’ The children completed the task, and their speech during it was recorded and coded for relevance ('related to task' or 'off task'); who it was directed to (self or examiner) and inaudible muttering (partially covert speech). Overall, the researchers found children with SLI/DLD performed less well on the Tower task. Those with SLI/DLD that did use private speech performed better at the task, but as a group they used less private speech than the control group. In addition, the control TD group demonstrated more partially covert speech than the SLI/DLD group. When both groups were asked to be silent, the control group outperformed the SLI/DLD group, and the authors suggested that this was because the SLI/DLD group were not using inner speech to support themselves at this point as they had not yet internalized their private speech, whereas the TD group were able to use internalized private speech strategies.

Other findings support the position that children with DLD show later internalization of private speech and develop use of inner speech at an older age than their typically developing peers. Lidstone et al. (2012) investigated the use of private speech in children with SLI/DLD aged 7-11 years through the Tower of London task. There were three conditions: no additional task; with articulatory suppression (children had to repeat a word whilst completing the task, which would be assumed to block private and inner speech) and with motor distractor (children to foot tap throughout the task, representing a control comparison condition for articulatory suppression using an additional task that would not be expected to block private and inner speech). They found that articulatory suppression resulted in poorer performance on the Tower of London to the same extent in both groups, suggesting that children with SLI/DLD were using an inner speech strategy that was being disrupted. However, more instances of overt private speech were observed in the children with DLD, suggesting that the children with DLD had lower levels of internalization. It was also reported that their overall performance on the task was poorer than that of the TD group, suggesting a general deficit in cognitive processing. This finding supports other reports in the literature of weaker executive functioning in children with SLI/DLD

(Archibald & Gathercole, 2007; Henry, Messer et al., 2012; Kapa & Erikson, 2019; Messer et al., 2019; Montgomery et al., 2010).

Botting et al. (2013) investigated whether verbal mediation – i.e., the use of an overt or covert verbal monologue for self - is used in the same way in children with SLI/DLD as children with typical language. This study looked at both private speech and specifically phonological encoding, using four short-term memory tasks: a non-verbal visual block pattern task (that could not be supported easily by verbal mediation); a task that involved copying a picture pattern by pointing (that could be supported by verbal mediation, specifically potentially phonological encoding – generating a verbal label for the picture to be recalled later by pointing); a third task involving verbal instruction but a non-verbal, pointing response (requiring verbal mediation/private speech in terms of retaining the instruction, but without requiring the encoding element); and a fourth task involving verbal instruction and requiring verbal response (which would require private/inner speech to process instructions and generate response). This was designed to show a 'gradient' of verbal demands, from little/none to a very verbal based task, requiring increasing levels of verbal mediation. Children with SLI/DLD demonstrated poorer performance than a control group on all except the non-verbal task that could not be supported by verbal mediation. These findings suggest that private/inner speech is impaired in children with DLD. It was not possible to tell whether this is because verbal mediation was not developed in these children, or because the children have learned to rely on visual strategies rather than utilize more specific strategies such as verbal mediation or indeed phonological encoding (Botting et al., 2013).

3.3 Verbal Rehearsal

The aspect of private speech this study is particularly concerned with is that of verbal rehearsal, a key part of Baddeley's working memory model (Baddeley, 2010). Verbal rehearsal refers to the refreshing of material to be remembered to keep it available within the short-term storage capacity of the phonological store, and its development correlates with developmental changes to working memory (Gathercole, 1998; Tam et al., 2010). This, along with an increase in articulation rate with age that would allow greater rehearsal, which occurs in real time, suggests rehearsal may drive increased memory span (Cowan, 2016). As children with DLD are delayed in their acquisition of language and the few studies into this suggest they are also delayed in the development of inner speech, we would expect a correlating delay in the use of verbal rehearsal strategies, alongside a reduction in the PSE and use of phonological encoding as these processes are so tightly related.

3.3.1 Working Memory and Verbal Rehearsal

Verbal strategies which support working memory involve private speech – either overt or covert use of language 'for self' to support recall. Phonological encoding is an important part of this because it represents the first step towards verbal rehearsal for information presented in a form that is not already phonologically encoded, in other words information that is not already 'verbal'. An example of this would be visually presented pictures which have easy to apply names (see section 5.4 for examples of such visual stimuli): such pictures would need to be converted into a verbal/phonological code using phonological encoding before they could be verbally rehearsed. Alternatively, if phonological encoding does not occur for immediate serial recall of lists of pictures, a visual strategy may be employed, where there is no phonological encoding, and individuals simply conjure the image of the to-be-remembered item in their head without 'saying' its name. However, this section focuses most closely on the process of verbal rehearsal and other similar strategies that require the articulatory rehearsal mechanism to be engaged in repeating (already) phonologically encoded information.

These verbal rehearsal strategies will be considered within the context of a verbal short-term memory task, i.e., serial ordered recall of a list of items that have verbal labels immediately after presentation. In these types of tasks, verbal rehearsal can be overt or covert and includes several types, listed here in order of increasing complexity: (1) 'Naming' - repetition of the last viewed item 'singly' within the articulatory rehearsal mechanism after each new item is presented; (2) 'Once Through' or 'Complete' rehearsal - repetition of the full list of 'to-be-remembered' verbal labels once within the articulatory rehearsal mechanism after all items have been presented; or (3) 'Cumulative' rehearsal - repetition of all items to be recalled in serial order together after each new item is presented, building up the size of the rehearsal 'set' with the presentation of each new item (see section 5.5.2).

Studying the use of these three specific verbal rehearsal strategies by children of different ages provides insight into the development of phonological short-term memory (PSTM). It is known that verbal short-term memory span increases with age (S. Miller, McCulloch, & Jarrold, 2015) and these developmental increases in span have been associated with increased speech rate, increased reaction time and/or faster processing time, or the use of more efficient verbal rehearsal strategies (Jarrold & Hall, 2013). Understanding the development of the use of verbal rehearsal strategies, therefore, could help to corroborate the development of the PSE – i.e., do the children who have shown a statistically significant PSE on a memory recall task also self-report using a verbal rehearsal strategy such as naming or cumulative rehearsal? Is this strategy use related to span length, or perhaps linked to language ability? Alternatively, does awareness of strategy use impact on actual strategy use? In other words, it may be possible to employ verbal rehearsal strategies without being aware of doing so, as evidenced by the studies showing adults and older children denying their use of private speech even when it has been observed (Poloczek et al., 2019).

Actively utilizing the articulatory rehearsal mechanism to keep phonological information in mind ('online') should allow longer periods of retention within the phonological store. Logie et al.

(1996) investigated PSTM effects and strategy use in adults. Participants were shown written words or heard words one at a time to recall, then immediately afterwards they were asked to repeat them in serial order. There were four lists – two of phonological similar/dissimilar and two of long/short words. Immediately after these tasks, participants were asked how they had remembered the items, without prompting. Those who reported verbal memory strategies, such as rehearsal, had a greater PSE than those who did not. Strategy choice, therefore, appears to impact the extent to which PSE is observed in adults. There is also some developmental evidence about self-report of verbal rehearsal considered in the next section. Overall, it is argued that the inclusion in this thesis of strategy self-reports could help in the analysis of observed PSEs (or not) in participants, leading to greater understanding of the development of verbal rehearsal strategies and verbal mediation.

Another important aspect of this rehearsal is for word learning. When a new word is heard, 'rehearsing' it in the phonological loop allows for a representation to be created than can be stored in the phonological store and long-term memory (Henry et al., 2020). If this process is disrupted, and rehearsal cannot take place, or cannot take place as efficiently, word learning is likely to be disrupted, and this challenge in encoding is thought to be a critical aspect in DLD (Jackson et al., 2021). The effect of this can be far reaching due to the 'boot-strapping' effect – the greater number of words in the phonological store, the easier it is to learn new words as similar representations can be used to form new words (Gray & Brinkley, 2011).

3.3.2 Development of Verbal Rehearsal Strategies

Previous work has suggested that there is a gradual development in verbal rehearsal-related strategies with age. For example, children up to 5 or 6 years are likely to use a simple naming strategy. By 10 years, more complex verbal rehearsal methods are used (e.g. rather than just saying the name of each item to be remembered, children repeat the names of all the items seen to date in a cumulative manner to aid recall) (Henry et al., 2000). This developmental progression has been tested using immediate verbal serial recall tasks and by asking children what kind of strategy they used immediately after each trial (Henry et al., 2012; Hulme et al., 1984; Poloczek et al., 2019).

Poloczek et al. (2013) found that a range of strategies was used in a verbal short-term memory span task in primary school-aged children (from 6-10 years), with individual children using a mix of strategies dependent on the trial. Naming or cumulative rehearsal were the most used strategies: 10% of children reported they 'always' used naming in the memory task, and 12% reported they 'often' used cumulative rehearsal. Further, 50% of children reported rarely using single verbal rehearsal or a visual strategy to support recall, and almost half (47%) reported that they used no strategy at all. Therefore, verbal strategy development appears to be somewhat complex, with little evidence for a clear transition at a particular age level.

As discussed in section 1.5 , evidence from the phonological similarity effect suggests that phonological encoding typically develops around age 6-7 years. Verbal rehearsal also appears to develop gradually, but somewhat later (7-9 years), although it may be prompted by cues from adults. For example, McGilly and Siegler (1989) questioned children during an auditory digit span task about whether they had used verbal rehearsal and found 24% of five year olds reported they did. However, the method involved prompting the children by reminding them they 'could say the numbers in their heads'. Overall, there appears to be an increase in verbal rehearsal strategies from age 5 to 9 years, with younger children more likely to repeat each item once (naming) or not at all, and older children being more likely to repeat the words all together, cumulatively. Even within one task, children can demonstrate different strategies on different trials, suggesting that verbal naming and rehearsal strategies develop gradually, rather than being 'all or nothing' and concurring with Siegler's overlapping waves theory (Siegler, 1999). Short lists well within memory capacity may also encourage simpler strategies such as naming or even no strategy, whereas longer lists may encourage cumulative rehearsal, although lists beyond span capacity may result in a return to the simpler methods due to excessive cognitive load.

In a related study by Lehmann and Hasselhorn (2007), 8 to 10-year-old children were shown pictures of nameable items at the same time as the examiner labelled them (i.e. there was verbal and visual input) and then were requested to recall as many pictures as possible. Free rather than serial recall was tested, so order of recall did not matter. Children were encouraged to do or say anything that would help, and all strategy behaviours were coded. These included repeating names (single-word rehearsal) or adding them on to the previous item/s (cumulative rehearsal), or just saying the name of the picture after they saw it (labelling – referred to here as 'verbal naming'). Similarly, although a trend of older children using more cumulative rehearsal strategies than labelling was reported, generally a mixture of verbal strategies for recall were seen as coexisting. The focus on phonological encoding and use of verbal rehearsal is important, because repeated exposure to items allows more opportunity to encode items and process in phonological store and long-term memory, which makes items easier to retrieve and harder to forget, as features are stored more clearly (Gillon, 2005).

This mix of verbal strategy use again suggests a 'waves of development' process rather than a linear staircase of increasingly complex strategies. Siegler (1999) suggests that children use multiple methods for cognitive processes on similar tasks, to 'try out' new strategies rather than directly replacing familiar methods, until it is certain that new methods are more efficient.

3.4 Self-reporting of Strategy Use

In the 1960s, it was observed that so-called 'private speech' was often used for verbal rehearsal in memory experiments and appeared to maximize performance (Flavell et al., 1966). As well as generating interest into research on the use of private speech in problem-solving tasks (G. A. Miller, 1994; Winsler & Naglieri, 2003), this also sparked interest in children's awareness of the strategies they used and whether this affects performance. Often, these two aspects are analysed separately – e.g. by observing spontaneous overt or partially covert utterances in younger children during a task and coding this as private speech (Lidstone, Meins, & Fernyhough, 2011); or by training older children to use verbal strategies (Winsler, 2009). More recently, there have been attempts to combine these approaches (Al-Namlah et al., 2006; Winsler & Naglieri, 2003). However, most studies have not shown a correlation between strategy use and task performance (G. A. Miller, 1994). Although not essential for effective strategy use, awareness often predicts strategy selection; and effectiveness of a strategy combined with awareness develops through middle childhood.

Most measures of covert verbal rehearsal involve self-reporting of the strategies used. Considerations of self-report include how spontaneous it is, and also that memory strategies may be unconscious such that if children are unaware of using them they will not report accurately (Flavell et al., 2000). Self-report data on strategy use can be effective if obtained immediately after each trial to ensure accurate report. Combining these reports with other evidence – for example, the presence or absence of a PSE, as well as physical behaviours such as mouthing or counting on fingers with recall – can be used to corroborate self-reported data.

Gathering strategy information can include observing how children respond, so an alternative method to self-reporting is to train children in various memory strategies and measure the change in performance before and after training. Improvement is, therefore, assumed to be due to the child adopting the trained strategy. S. Miller et al. (2015) adopted this method with the Brown-Peterson task and investigated the impact of training on TD children aged from 5-12 years. This is a serial recall task, where children are asked to recall images they have been shown after a filled delay. The delay includes either a visual or verbal distractor. If children trained in covert verbal rehearsal are less impacted by the visual than verbal distractor, it is assumed they are using the strategy of covert verbal rehearsal during the delay period.

Three groups were 'trained' by computer – the control group with no method of remembering; the verbal group by the computer labelling all pictures shown so far (cumulative rehearsal), and the visual group by being shown all the pictures so far. An examiner then asked the children how the computer 'remembered'. The distractor tasks after the pictures to be remembered were presented involved either identifying a rhyming picture (verbal distractor) or visually similar picture (visual distractor).

The findings showed that younger children had poorer recall overall than older children (as would be expected with developmental improvements (Baddeley, 1986)). Training of either strategy resulted in a significant advantage over the control group. Both the control and verbal strategy group showed a greater impact of a verbal distractor; the visual group were not impacted even by a visual distractor. Processing time was longer on the verbal tasks than the visual tasks. The authors concluded there is evidence that even children younger than 7 years use verbal rehearsal and phonological encoding because of the different type of training and impact of verbal distractors in this task.

However, methodological considerations of this study include the input and output requirements of the task. Children recalled verbally, activating articulatory motor areas of the brain, and not just using sub-vocal methods. This was the same in verbal and visual tasks – apart from not controlling for only 'inner' speech use, this means the visual tasks also required an element of verbal recall and would have drawn on dual coding methods. Additionally, the increased processing time of the verbal task could mean the verbal distractor task was 'harder' than the visual alternative, and hence not comparable, resulting in the greater impact of a verbal distractor on results. A final observation was that children trained in a visual rehearsal strategy were observed to use fewer verbal responses than those trained verbally.

Henry et al. (2000) also investigated verbal strategy use in children from aged 4-10 years, using the word length effect phenomenon. Children aged 4, 7 and 10 years were presented with lists of words to be remembered of either 1 or 3 syllables, at a span length appropriate to their age, and at a length of one more than this. The participants were randomly split into two groups. Half were presented with the words in the auditory modality (examiner said the words to the children); and half were presented with the words visually (examiner showed them a picture of the words). Recall was tested non-verbally through a probed recall design – children had to select which word had been presented in a specific serial position. A significant difference in recall depending on short versus long word length was seen only in the 7- and 10-year-olds, providing generally supportive evidence that only the older children used verbal rehearsal (hence obtaining the word length effect). Children were asked to report what strategy they used – cumulative rehearsal, naming or other. Reaction times were also recorded and used to predict strategy – a longer reaction time was assumed to be due to rehearsal. In line with this, there was an increase in reaction time from ages 4 to 7 years, thought to be due to the emergence of rehearsal over naming extending the response time. The relationship of reaction time to phonological encoding will also be explored further in section 4.1.

Henry et al. (2000) also noted that the child's reported strategy did not show an interaction with the word length effect or the presentation type (auditory or visual), but 10-year-olds reported more cumulative rehearsal with auditory presentation, whereas there was no difference for 7-year-olds. Additionally, children who reported cumulative rehearsal scored higher on a baseline vocabulary assessment.

3.5 Strategy use in children with DLD

As a result of this background, the current study aimed to develop further understanding of the development of rehearsal strategy use. From the literature, we expected to see more cumulative rehearsal strategies reported by older participants, and potentially only in older participants with higher vocabulary scores. Rather than a qualitative jump, it also seemed likely that an overlap of simpler (naming) and more complex (rehearsal) verbal strategies being used concurrently between and even within trials would be observed (Poloczek et al., 2013). However, it is unclear whether the use of cumulative rehearsal improves memory span; or if memory capacity limits cumulative rehearsal use (Jarrold & Hall, 2013). Strategy choice may relate to memory span broadly, in that those with lower memory span may be more likely to use a naming method, and those with higher spans cumulative rehearsal. As a result of this it seems plausible that children with DLD may use different memory strategies to age matched peers – as a result of their lower vocabulary scores and lower memory spans.

There is a gap in the evidence base regarding the use of verbal rehearsal strategies in children with DLD. The findings that are described point to the potential importance of strategy use in memory performance, mediated by a level of private and inner speech. As the use of inner speech appears to be delayed in children with DLD, it is hypothesized that use of specific verbal rehearsal strategies will be affected in the same way and verbal rehearsal strategies will not be deployed until a later stage of development than chronologically age matched peers. This may in turn then limit working memory performance. In addition, little is known about whether children with DLD differ in their awareness levels of the use of strategies and how that might impact working memory development and ability.

3.6 Summary of Chapter 3

In summary, it appears that children become more adept at using increasingly complex memory strategies as they develop, but at present there is no clear research investigating the development of use of strategies such as verbal rehearsal, and whether these develop as expected in children with DLD. This study therefore aims to gather information from children via self-report methods to better understand whether these strategies are comparable with TD children. Combining findings from the strategy choice with PSE data will provide a fuller picture of the development of phonological encoding in children with DLD between the ages of six and ten years.

Research Question 2:

Are the age differences in verbal naming and verbal rehearsal strategies the same in children with DLD between 6 and 10 years as their age and non-verbal IQ matched typically developing peers?

The final aspect of phonological encoding to be investigated will be that of its relationship to some related processes that may impact verbal mediation, and/or predict the development of the PSE.

CHAPTER 4

The Phonological Similarity Effect and Related Cognitive Processes

The process of generating a phonological code in order to recall an item during a working memory task is complex and can involve many associated systems. For example, when looking at a picture of a common item, e.g., 'dog', a child must be able to respond to the instruction to look at and remember it; to visually identify the picture and hold this representation in the visuospatial sketchpad; to retrieve the verbal label from the phonological store and then process it in the articulatory rehearsal mechanism (in real time). If the task also requires a verbal response the child must then produce the label themselves. If the visual stimulus is a written word rather than a picture, this then requires encoding of a grapheme into a phonological representation to generate a verbal label of the word (and access the associated semantic representation).

As a result, there are many adjacent skills that could impact phonological encoding, including speech rate (for rehearsal); processing time; reaction speed; expressive vocabulary and reading ability. Performance on a range of short-term memory tasks tend to be better in children who have faster rates of articulation (Baddeley, 1986; Cohen & Heath, 1990), good vocabulary (Gathercole & Baddeley, 1989; Gathercole, Willis, Emslie, & Baddeley, 1992; Michas & Henry, 1994); and have good oral language skills (Speidel, 1993); and/or are good readers (Leather & Henry, 1994). Consequently, previous research findings suggest there could be relationships between a range of children's abilities and a focal measure of inner speech such as the PSE.

Given that much research on inner speech and the phonological loop has focused on a limited set of measures, it is hoped that extending the range and type of outcome measures will add to our understanding of these processes, through regression analyses identifying any specific contribution to PSE results. This section will therefore outline previous research and describe the rationale for the inclusion of these additional factors and how they have been measured.

4.1 Reaction time and Rapid Automatic Naming

Increased processing speed allows quicker word recognition and learning (Marchman & Fernald, 2008) and is strongly related to working memory (Fry & Hale, 2000). It is thought that children with DLD have reduced speed of processing compared to peers with typical language (Montgomery & Windsor, 2007; Montgomery et al., 2010). If processing speed limits working memory (Bayliss et al., 2005; Towse & Hitch, 1995; Towse et al., 1998), then in a group with known working memory difficulties we would expect to see similarly a reduction in processing speed, evidenced by reaction time.

Reaction time is strongly related to lexical and grammatical development (Fernald, Perfors, & Marchman, 2006). A correlation between processing speed and phonological encoding is therefore logically expected – children with faster processing speed are more likely to use phonological encoding (evidenced by higher PSEs) and potentially to use more verbal rehearsal methods such as cumulative rehearsal, due to having more time to carry this out in a memory recall task. This will be measured with a simple reaction time task. Children must press a button as soon as a picture appears on the screen. No manipulation of the stimulus is required, just a response. A faster reaction time could mean that children begin the encoding process faster and are more efficient at it, resulting in more rehearsal time. In the same vein, children with a longer reaction time would be thought less likely to produce PSEs, because the reaction time is linked to DLD and a longer processing time.

However, focussing on verbal rehearsal strategies, reaction times have also been implicated in strategy selection – with longer reaction times suggesting rehearsal is occurring (Henry et al., 2000). Because the articulatory rehearsal mechanism occurs in real time, a longer response time may suggest children are rehearsing the stimuli internally using inner speech before recall. Children who respond more quickly may not be using a rehearsal strategy, resulting in the faster response. This could particularly affect cumulative rehearsal time, where each new stimulus is added on to any previous stimuli, so the reaction time may increase with each item (Poloczek et al., 2019) rather than simple naming which would not take as long in real time. Considering the relationship between reaction time and reported strategy could therefore also be useful to identify if there is a link between a longer response time and a reported verbal rehearsal strategy.

Another method of measuring processing speed is Rapid Automatic/Automatized naming (RAN) tests. RAN tests assess language production fluency and require participants to name shapes and colours as fast as possible. Children look at a series of pictures of different coloured shapes and must label them out loud as quickly as possible. This task requires phonological encoding, as the child must convert the visual stimulus into a verbal label. In addition to accessing the required lexical label, the child must inhibit the incorrect responses which are primed due to the task requiring repetition of the same shape/colours but in different combinations. As a result, faster processing speeds results in faster responses. RAN difficulties are also associated with language disorders, due to the need for retrieval of representations from the lexicon and adequate vocabulary knowledge (Semel, Wiig, & Secord, 2003; Wiig, Semel, & Nystrom, 1982). A slow response on the RAN task suggests some interference in working memory, either due to short term memory impairment or naming difficulties.

Children with less efficient phonological encoding would therefore be expected to have slower RAN scores, as it would take them longer to access the label required. Indeed, children with SLI/DLD are found to be slower and less accurate at RAN tasks than their typically developing peers (Katz et al., 1992; Ramus et al., 2013). Although it is not possible to say from this alone that the cause is phonological encoding (due to the other requirements of the task, for example production of a motor output plan), it could be a sign that phonological encoding is impaired in children with DLD if there is a pattern shown between lower RAN scores and a smaller PSE.

4.2 Speech Rate

Also linked to processing speed is speech, or articulation, rate. Overall, performance on phonological short-term memory tasks tends to be better in children with faster rates of speech (Baddeley, 1986).

Speech rate is the speed at which a person can repeat single words, pairs or triads of words over and over. Speech rate correlates with immediate memory span in both adults and children (Henry, 1994; Montgomery et al., 2010) , and even if this reflects the impact of the phonological complexity of the memoranda or the time taken to recall these items, developmental changes in speech rate could drive age-related improvements in short-term memory performance (Jarrold & Hall, 2013). As a result, we would expect similar correlations between lower speech rate and poorer working memory performance e.g., between children with DLD and TD peers.

Developmental improvements in speech rate are related to increases in phonological short-term memory (PSTM) and this development has been proposed as an explanation for age-related increase in working memory capacity (Hitch, Halliday, Dodd, & Littler, 1989; Hulme et al., 1984; Roodenrys, Hulme, & Brown, 1993). PSTM increases with age – at 5 years, memory span is roughly two-three words, increasing to four-five words by 9 years in typically developing children (Henry et al., 2012).

Speech rate is reported to be lower in children with SLI/DLD (Hasselhorn & Grube, 2003) and this could therefore be a contributory factor to a reduced PSE in this group. As a result, children with a slower speech rate require more time to rehearse (which occurs in real time) and therefore they are less able to use the rehearsal strategy to aid recall, contributing to a poorer memory span.

It is possible that children with DLD are less efficient in their ability to recall words from the phonological store. Children with DLD have less well-formed representations (Jackson et al.,

2021) which makes it slower and harder to retrieve from long-term memory and the phonological store (Ylinen & Nora, 2020). As the stored form-referent is not precise (the representation is not a good 'match' to the input), a new motor plan may need to be created from the articulatory rehearsal mechanism for children to form the words. Overall, this process could take longer, resulting in less time for rehearsal and therefore reduced strategy use and likely lower PSE (due to lack of comparison to stored representations causing the 'confusion').

Calculating speech rate in this study will allow investigation into whether children with DLD have a significantly slower rate of speech than children with typical development. If a difference is found this will replicate previous research and support the idea that reduced speech rate could be contributing to their poorer memory span.

General speed of processing has also been found to predict reading ability (Catts, Gillispie, Leonard, Kail, & Miller, 2002), and RAN is associated with general literacy difficulties, in particular reading difficulties.

4.3 Reading Difficulties

An overlap between DLD and reading disorders such as dyslexia has been widely discussed and will be explored in the following section.

Phonological working memory predicts later reading development (Palmer, 2000a) and there is a strong correlation between memory span and reading age (Johnston, Rugg, & Scott, 1987). Working memory is a predictor of variance in reading in primary aged children (Berninger et al., 2010; Booth et al., 2014) There also is a considerable comorbidity between children with reading difficulties and DLD. 51% of children with impaired language have reading difficulties; 55% of children with reading difficulties have language impairment (McArthur, Hogben, Edwards, Heath, & Mengler, 2000). In addition, oral language can predict later reading ability (Murphy, Justice, O'Connell, Pentimonti, & Kaderavek, 2016). Children with poor reading skills at age 7 are often found to have had delayed language acquisition (Bishop & Adams, 1990). A difficulty with phonological encoding could therefore be part of the cause of both conditions.

Phonological encoding is implicated in reading (Perrone-Bertolotti et al., 2014) as phonological encoding is required to translate graphemes into sounds and assign them phonological representations – i.e. changing a visual stimulus into a phonological representation, indirectly accessing the phonological store. When learning to read, it is thought that a phonological pathway maps orthography (printed words) to phonology (spoken words) and a semantic pathway simultaneously maps orthography onto phonology via semantics (meaning). In order to decode words, sounds must be held in the working memory and then joined together via the articulatory rehearsal mechanism. Converting the orthography into a phonology involves phonological encoding.

It is also known that many children with DLD struggle with both language and literacy (Bishop et al., 2009; De Bree et al., 2012). There appears to be a large overlap between DLD and dyslexia, although evidence suggests these are distinct disorders that commonly co-occur (Ramus et al., 2013). Schuchardt et al. (2013) found that children with DLD *and* dyslexia demonstrated more significant phonological loop impairment than children with only dyslexia, and Gray et al (2019) found that the same group with the double deficit had lower working memory than children with only one of these conditions. Phonological processing impairments in preschool have repercussions in language development (Chiat, 2000).

The evidence that there is an overlap between phonological encoding and ready suggests that the children who have most difficulty with the main phonological encoding task will also score lower on the reading assessment, and there will be a correlation between size of PSEs and reading ability.

A potential clinical marker of DLD/SLI is non-word repetition tasks (where children must reproduce a word that is linguistically permissible in their language but does not exist, so they do not have a stored motor plan for it) (Conti-Ramsden et al., 2001). Children with dyslexia also have trouble with non-word repetition (Melby-Lervåg & Lervåg, 2012) suggesting some comparable difficulties with working memory. Children with non-word repetition difficulties have poor language and literacy skills – poor phonological short-term memory may be indicative of domain general difficulties and impacts language difficulties across all domains (Conti-Ramsden & Durkin, 2017). However, poor phonological processing is not solely responsible for poor reading. There are other contributory factors, namely syntactic and semantic ability, which may have more of an impact on reading ability than phonological processing alone (Bishop & Adams, 1990). In summary, there is a high chance of reading difficulties in children with DLD (Catts, Adlof, Hogan, & Ellis Weismer, 2005).

Reading also requires the suppression of the visual memory, as this does not support sequential and temporal processing of information in the memory, but it rather is better suited to holistic processing (Palmer, 2000a). For remembering, therefore, phonological processing is more efficient. Generally, it appears that children replace the visual memory preference with a phonological encoding preference around age 7 (Henry, Messer, Luger-Klein, et al., 2012). This is beneficial for reading, as visual memory stores words holistically, and for decoding it is beneficial to break words down into the sounds to create the phonological representation. There is some evidence that children with reading difficulties continue to use visual memory for longer than their peers, which could impact their use of phonological encoding and reading ability (Palmer, 2000a). PSE has been found to be reduced in poor readers compared to age matched controls, but not to reading matched controls, suggesting that phonological encoding is not the issue with reading and memory in these children, but instead there is a general delay (Johnston et al., 1987). However, qualitatively this study found that the good readers described a verbal memory strategy that was lacking in the "poor reader" group: further evidence that there is a link between working memory and literacy skills, and also perhaps that explicit meta-awareness of strategies aids memory.

There is also some evidence that adults who are less literate than others use more private speech (Alarcón-Rubio, Sánchez-Medina, & Winsler, 2013). As well as suggesting that formal education may support self-regulatory behaviours and the development of verbal mediation, the link between DLD and literacy suggests that as children with DLD are more likely to have literacy difficulties (Palmer, 2000a), this could be further evidence that those with reading difficulties and/or DLD could have less internalized and more 'immature' private speech.

Collecting information about our participants' reading ability and comparing this to their PSE levels and self-report of strategy, could reveal if this is a difficulty in poor readers with DLD.

4.4 Expressive Vocabulary

The final area to be considered in terms of association with phonological encoding is that of expressive vocabulary. Correlations between word knowledge and language development and cognitive processing suggest high overlap with working memory processes. Of course, by its nature DLD impacts expressive vocabulary, being one of the most consistent markers in an extremely heterogenous demographic – while significant differences between the profiles of children with DLD are often observed, e.g., those with expressive difficulties; those with receptive and expressive difficulties; and those with receptive difficulties in the presence of relatively preserved expressive skills – the expressive element is the most consistent (Conti-Ramsden, 2008).

This appears to be directly linked to phonological short term memory abilities. In order to acquire new words and store them in order to use, children must be able to encode the information accurately. Many studies have shown that children with DLD demonstrate an impairment in this area (Jackson et al., 2019). If similar words are already stored, this process is sped up by having a 'blueprint' that can be used, permitting 'fast mapping' or 'bootstrapping' to learn further words. The smaller vocabulary reduces the potential of the fast-mapping process, and impacts acquisition (Archibald, 2018).

In the context of this thesis, it seems highly likely that a relationship between expressive vocabulary and phonological encoding will be found – as it also impacts in both directions: if children are impaired in the encoding process initially it is hard to form new representations. If they have fewer representations stored, they are limited in their ability to 'fast map' and retrieved representations to aid with encoding.

Knowing that children with DLD have difficulties with naming it seems possible that the mechanism may be connected – therefore measuring reaction speed and naming ability may show correlations with phonological encoding, although it appears that working memory capacity has a greater role in language limitation than processing speed (Leonard et al., 2007; Montgomery & Windsor, 2007).

4.5 Summary of Chapter 4

Related to phonological encoding, speech rate, reaction time and rapid automatic naming, are expected to show a relationship with the PSE, generally with faster speeds or higher scores being associated with higher levels of PSE, and/or reported use of verbal rehearsal strategies. This is because phonological encoding relies on the articulatory rehearsal mechanism, which occurs in real time, and if responses are slower, or speech rate takes longer, there is less opportunity for rehearsal. For reading ability, this is expected to correlate with observation of PSE because of the phonological encoding required for reading tasks. A similar process – the translation of visual input into verbal label – is involved in decoding words, as it is to labelling pictures. Together with the evidence of the high overlap of reading difficulties and DLD it seems highly likely the common mechanism that underlies them will be impacted in all these areas.

Research Question 3:

> Are there similar relationships in the DLD and TD groups between PSE and the following variables: Reaction time, RAN, speech rate, reading and expressive vocabulary?

DLD is an important disorder affecting many children and the focus of a range of interventions by speech and language therapists. Research funding on DLD lags behind that of many other disorders (McGregor, 2020), despite a strong focus on DLD currently in the UK and abroad – (e.g., the 'RADLD' campaign and a focus on 'rebranding' to raise awareness and develop evidence base). As a result, there is currently a gap in the literature regarding the development of phonological encoding in children with DLD and how/if this progresses through early and middle childhood.

Investigation into the working memory system of children with DLD found evidence that as well as difficulties in the verbal domain, the central executive and the visuospatial systems are also affected, suggesting widespread working memory difficulties. However, most research has focused on the impairment of phonological short-term memory, which has been implicated in the causation of the disorder. This has found that PSTM is impacted in children with DLD. However, comparatively little attention has been paid to the operation of phonological encoding and other processes which can be considered to involve verbal mediation such as private speech, even though private speech was regarded by Vygotsky as crucial to socio-cultural development and to self-regulation of cognition and behaviour (1987). Dysfunction of private/inner speech could therefore result in cognitive impairments and/or poor self-regulation (Alderson-Day & Fernyhough, 2015). In addition, if private/inner speech are affected, it is likely verbal rehearsal is also affected, and verbal rehearsal supports PSTM.

This thesis aims to provide some of the research to fill this gap and identify potential clinical targets for therapeutic intervention. The next section will introduce the methods used to collect these data on phonological encoding, and the following chapters will go on to present the analyses and discuss the results.

CHAPTER 5

Methodology

This chapter describes the design of the research project, including recruitment of participants; exclusion and inclusion criteria and all standardised and experimental measured employed throughout. Ethical approval for this project was given by the NHS National Research Ethics Service Committee, London (Surrey) (Appendix A).

5.1 Research Design

The study employed a mixed design, with two between-participants factors: group (with two levels; DLD vs TD); and age (with two levels: younger vs older children). For the investigation of phonological encoding there was within-participants measure of picture type (with two levels: phonologically similar (rhyming) or phonologically dissimilar (non-rhyming) picture names. Order of presentation of picture type (rhyming then non-rhyming or vice versa) was counter-balanced between participants.

5.2 Recruitment

Participants were recruited from 2018-2020 through approaching local mainstream primary schools and language units in London. The DLD group were identified by school SENCos or NHS Speech and Language Therapists, who distributed the participant information and invitation letter to children known to have DLD. The TD group were recruited by class teachers distributing the invitation letter to whole year group classes (year 2 and year 5). Children underwent screening to ensure they were placed in appropriate group (i.e., no children with undiagnosed DLD were placed in TD group).

After response to the invitation letter, the researcher rang and spoke to parents and talked through the participant information, and if they were happy to proceed returned a signed consent form.

Each child participant was seen individually in their school and given an accessible version of the participant information that was also spoken through, before they were asked to complete an assent form. It was reiterated that participation was voluntary and could be withdrawn at any time without explanation or penalty. Those that assented then commenced the screening.

From March 2020, when the COVID-19 pandemic began, recruitment method changed to reflect the necessary reduction in face-to-face contact. Advertisements were placed in Facebook groups, on Twitter and in the E-DLD newsletter for participants (with revised ethical approval) and consent was gathered through online 'Qualtrics' survey forms. Phone or Zoom contact to discuss the participant information and consent remained. During the first session, this was all repeated in accessible form to child participant.

All participant information forms, invitation letters and recruitment advertisements can be found in Appendix B.

5.2.1 Impact of COVID-19 restrictions

Due to the COVID-19 pandemic, face to face testing was forced to cease in March 2020. At this point, 83 participants had completed the tasks (49 with DLD, 33 typically developing).

The protocol was adapted to be administered remotely - for the main memory task, a link was emailed to the participant's parent/carer with log in details. They shared their screen over Zoom so researcher could introduce and explain each task and see the child's selections, which were made either by the child directly or parent clicking where the child pointed for some of the younger participants.

A visualiser was used by the researcher to administer some of the screening tasks if paper materials were required e.g., CELF sub-tests, TOWRE, BAS. Revised ethical approval for this adaptation was sought and provided by the NHS HRA Research Ethics Committee (found in Appendix A).

A further 50 participants were tested remotely (24 DLD; 26 TD).

Independent *t*-tests comparing the non-verbal IQ scores and language scores of the groups tested face to face or online showed no significant difference, suggesting consistency regardless of the modality of test administration (see Appendix C for table of statistical test results).

5.3 Participants

The sample contained 132 children: 69 children in the 'younger' group aged 6 to 7 years (mean age: 6 years 7 months, *SD* = 6 months; 41 boys) and 63 in an 'older' group aged 9 to 10 years (mean age: 9 years 7 months, *SD*: 8 months, 27 boys). Children attended mainstream schools or language units attached to mainstream primary schools in England. Table 5.1 summarises participants' mean scores for demographic details and language and non-verbal scores.

Children with known hearing loss, major physical disability, or a definitive diagnosis of ASD or learning difficulties were excluded from the study. All participants had non-verbal IQ scores of 70 or above based on the Matrices subtest from the British Ability Scales 3 (Elliot & Smith, 2011). Only children whose entire schooling had been conducted in English were included.

Written, fully informed consent was obtained from parents/carers and assent was obtained from children (using a specially worded form) prior to testing.

Table 5.1 Summary details of all participants - mean (standard deviation) for age, sex, gender, non-verbal and language scores for each group

	Age	Sex		BAS-III	CLS
	Mean (SD) (years; months)	**Female**	**Male**	**Mean (SD)**	**Mean (SD)**
All DLD (*n* = 73)	7;11 (1;06)	36	37	46.78 (3.96)	54.64 (12.66)
All TD (*n* = 59)	8;06 (1;07)	28	31	47.80 (4.36)	105.27 (16.01)
All 6-7 years (*n* = 69)	6.58 (0.51)	28	41	47.13 (4.01)	75.90 (30.29)
All 9-10 years (*n* = 63)	9.58 (0.67)	36	27	47.35 (4.33)	78.78 (27.65)
6-7 years DLD (*n* = 40)	6.63 (0.50)	17	23	46.08 (4.10)	52.78 (12.82)
6-7 years TD (*n* = 29)	6.51 (0.52)	11	18	47.21 (3.96)	107.79 (13.48)
9-10 years DLD (*n* = 33)	9.60 (0.51)	19	14	46.42 (3.80)	46.91 (12.29)
9-10 years TD (*n* = 30)	9.55 (0.82)	17	13	48.37 (4.71)	102.83 (18.02)

5.3.1 Language Ability

The Clinical Evaluation of Language Fundamentals 4th Edition UK (CELF-4 - Semel, Wiig, & Secord, 2006) is a widely used assessment of language abilities, and as such its Core Language Skill sections were used to assess language skills: Concepts and Following Directions (C&FD); Word Structure (WS); Recalling Sentences (RS) and Formulating Sentences (FS). This test provides standardisation data from a UK population and offers an omnibus measure of language ability (Karasinski, 2015) covering a range of receptive and expressive language tests.

Children who scored <-1.25 SD below the mean on the Core Language Scale were included in the DLD group (Reilly et al., 2014). Children in the TD group were required to score a scaled score of 7 or above. The CELF-4 is an accurate measure for identification of DLD due to an optimal balance of sensitivity and specificity (Spaulding et al., 2006). The reliability of the CELF-4 was evaluated from 320 students, and stability coefficients from .71 to .86 for subtests and .88 to .92 for composite scores based on the standardisation population. Internal consistency using Cronbach's alpha ranged from .69 to .91 for subtests and from .87 to .95 for composite scores. The inter-scorer decision agreement for subtests that required clinical judgement ranged from .88 to. .99 (Semel et al., 1995).

5.3.2 Non-verbal cognitive ability

The Matrices sub-test of the British Ability Scales 3rd Edition, or BAS3 (Elliot & Smith, 2011), is a non-verbal cognition test which presents the child with a series of patterns from which one piece is 'missing'. The child is instructed to look at the pattern and select (from six alternative options) the one and only piece that can complete the pattern. The test is split into three sets of twelve patterns each. Each set begins with simpler and progresses to more complex patterns. The child's responses were noted and afterwards scored as correct or incorrect. The total score was then compared to age-relevant population norms and an IQ score assigned. Children who scored a T-score of under 70 were excluded from the sample, as IQ scores of more than two standard deviation below the mean are in the range of intellectual disability (American Psychiatric Association, 2013) The BAS3 is a valid and reliable test, with Test-retest reliability is reported as .73 for the Matrices subtest (Elliot & Smith, 2011)

Normality tests demonstrated the non-verbal IQ scores obtained by the participants were normally distributed across groups (DLD $w(73) = .967$, $p = .054$; TD $w(59) = .063$, $p = .054$).

5.3.3 Matching of participants

The control group were selected to ensure that key variables beyond language ability were matched. Using a purely chronologically age-matched control group is inappropriate if one wishes to check whether the clinical group is less able than similarly chronologically aged children as the TD children is highly likely to differ on a number of language related abilities and when compared to a group with developmental delay, a difference in performance may be due to a regression to the mean in the TD group (Taylor et al., 2014). Matching for non-verbal IQ as well as chronological age, therefore, reduces this risk. Language matched controls were not included in this study, as to find a group with language levels similar to the DLD group would have involved a much younger group of children for whom the experimental tasks would not have been suitable. The differences in life and other experience between the groups with and without DLD could, therefore, confound the results (Bishop, 2014b).

To ensure matched groups, comparisons were made between the TD and DLD groups. Independent *t*-tests confirmed there were no significant differences in age (Older age group - $t(61) = .28$, $p = .779$, $d = .67$, Younger age group $t(65) = 1.03$, $p = .308$, $d = .51$); sex ($t(128) = -.19$, $p = .846$, $d = 0.50$) or non-verbal IQ ($t(128) = -1.22$, $p = .225$, $d = 4.14$).

5.4 Apparatus and Materials

Two sets of nine easily nameable, familiar pictures were used. Each picture was presented on a laptop computer as a 5 x 5 cm black on white line drawing using Gorilla software (www.gorilla.sc/about). All pictures were of familiar, highly imageable objects, which were hand drawn in pencil and black ink on white paper using the same straightforward style of depiction, as used in Henry et al., 2008. These were then scanned as images for reproduction. Examples of picture materials used can be found in Figure 5.1 and Figure 5.2

Figure 5.1 Phonologically dissimilar stimuli used for Memory Span task

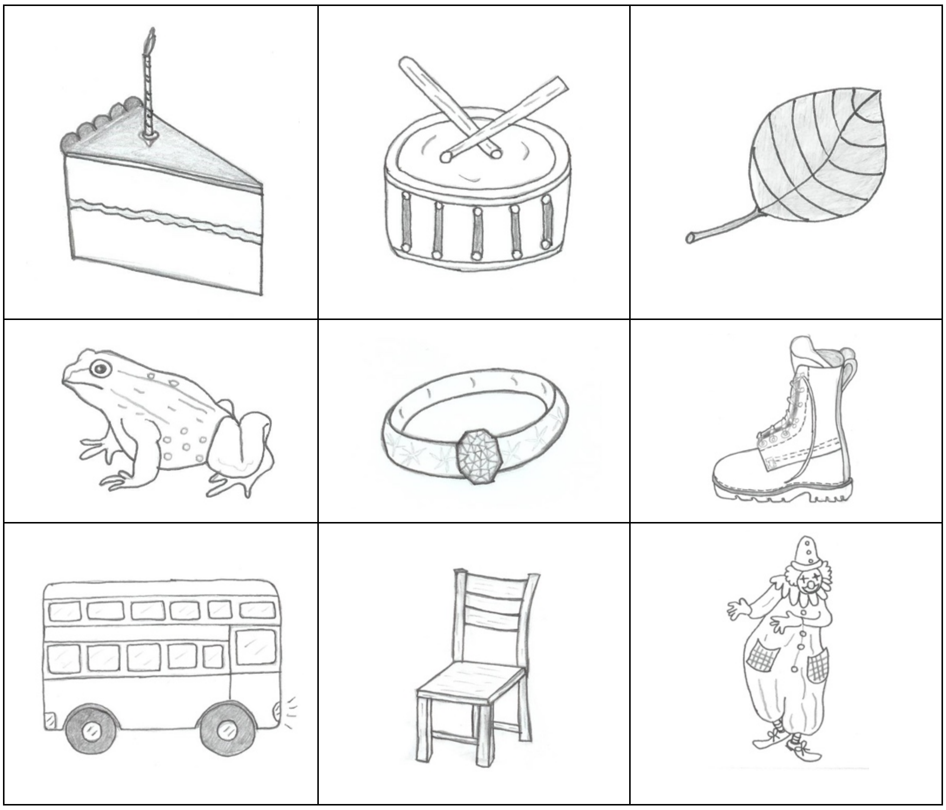
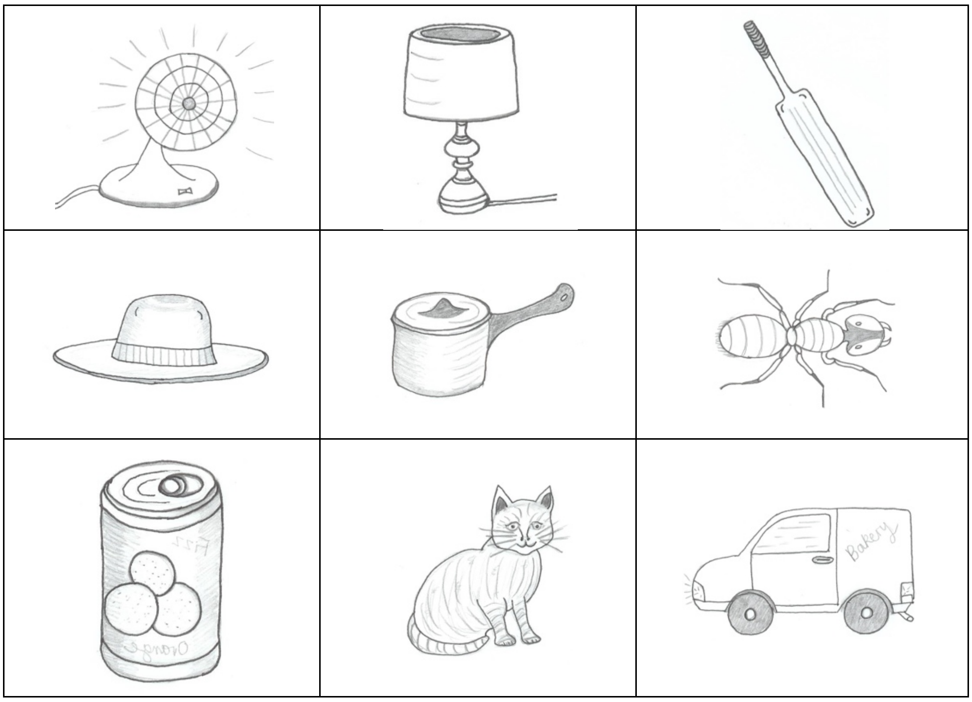


Figure 5.2 Phonologically similar stimuli used for Memory Span task



One set consisted of control items, and these had names that were phonologically dissimilar (cake, chair, shoe, bus, leaf, frog, ring, clown, drum).

The second set of phonologically similar items had names (can, lamp, hat, van, pan, ant, cat, bat, fan) that shared the same vowel, [æ], regarded as the most important factor for phonological similarity (Nimmo & Roodenrys, 2005).

Items in each set were visually dissimilar to limit any potential visual similarity effects (Palmer, 2000a). Item sets were matched as closely as possible in terms of mean age of acquisition of object names, imageability, frequency, familiarity, and name agreement (Morrison et al., 1997), although ratings were not available for two items in the phonologically similar set (fan, can), due to constraints in selecting appropriate materials, they were included.

Responses on the memory trials were always non-verbal, hence children recalled lists by selecting a picture from a visual array of all items in a particular set. This was implemented using a 'response' screen with a 3x3 matrix featuring all nine pictures. This response screen was displayed after the presentation of each to be remembered list of individual items, for the participants to tap or click on the pictures they had seen in the correct order. This removed any requirement for verbal response. There were five response screen matrices for each set of stimuli, which all differed by containing a random arrangement of the nine objects from that set. The response screen matrices were changed after each trial; this prevented participants from learning the spatial locations of the items during the recall phase on each picture memory span task.

5.5 Procedure

Children were tested at their school, home or clinic depending on parental choice; or over Zoom (child supervised by parent, and researcher leading the session remotely) - see section 5.2.1 for detail regarding changes due to the COVID-19 pandemic.

The testing took place in two sessions of approximately 45 min, depending on the child's and/or the parents' choice. In the first session, the CELF-4 Core Language Composite sub-tests and the BAS3 matrices subtest were administered in the following order: Concepts and Following directions; Word Structure; Recalling Sentences and Formulated sentences; Matrices. These were scored to ensure inclusion criteria were met – BAS3 score over 70.

In the second session, participants completed the Memory Tasks and additional measures (Reaction Time, Speech Rate, RAN, TOWRE and Naming) in this order, followed by a repetition of a shortened Memory Task with questions about strategy used.

The sessions were child-led and involved breaks as required. Children were encouraged and praised throughout, with tasks designed and presented as games to motivate participation.

5.5.1 Memory tasks

The experimental memory tasks for both age groups of children were administered as follows, replicating the method of Henry et al. (2012) but using Gorilla psychology software to administer the task on a computer or tablet.

The lists comprised the two sets of pictures with either phonologically similar or dissimilar
The order of experimental picture memory span tasks (phonologically similar or dissimilar) was counterbalanced and for all children, a small set of practice items (*n* = 4) was used to illustrate how the memory span task proceeded. Before each picture memory span task, the child was presented with all items in the relevant set (i.e., four items in the practice set and nine items in each of the experimental sets), and all objects were named for them by the experimenter to ensure that children were familiar with all presented items and their names. None of the children appeared unfamiliar with any of the items in the pictures. Children were told not to name the pictures. This was to reduce priming any phonological strategies and they were reminded to remain silent if they did try to say the names.

Following this, the memory span tasks were administered, starting with the practice items. Participants were asked to look at a series of pictures on screen, presented one at a time, and to recall the sequence of pictures in the same order by tapping or clicking each image in turn on the response screen. The importance of a record of serial order has been documented (Nimmo & Roodenrys, 2005). Each picture was presented for 1.5 seconds on a screen directly in front of the child and then disappeared. As in Henry et al. (2012), to make the test comparable with verbal memory tasks, spatial cueing opportunities were removed from the procedure by showing the pictures in the same position in space rather than in a fixed horizontal row (Hitch, Woodin et al., 1989; Hitch et al., 1991; Hitch & McAuley, 1991; Longoni & Scalisi, 1994).

The memory span part of the experiment began with the set of four practice pictures and practice span trials of both one and two items; once the child understood the task, he or she moved on to the experimental trials using the rhyming and non-rhyming picture sets.

To determine the maximum number of items a child could recall on each experimental span task, up to six lists were administered at any given list length. Experimental trials started with a list length of one item. For each list length, if the child passed fewer than four trials, they were deemed not to have passed that span level, and testing ceased. If the child passed at least four of six trials, list length was increased by one item, and another set of trials started. Each time a higher list length was introduced, children were informed about how many pictures next would be shown to them, and they were reminded each time to point to them in the correct order. Children were instructed not to name items out loud during presentation of pictures in order to avoid adding overt verbal input (Hitch et al., 1991). If they were observed to do so, they were reminded again. Some children required prompting about this rule before each presentation.

The order of experimental picture memory span tasks (phonologically similar or dissimilar first) was counterbalanced according to a Latin square. No significant difference was found for order of presentation ($t(130) = 0.25$, $p = .804$, $d = 0.50$).

Split-half reliability for total trials correct calculated using Cronbach's alpha demonstrates very high internal consistency, $\alpha = 0.939$ for phonologically dissimilar pictures, $\alpha = 0.923$ for phonologically similar items. This provides reassurance as to the consistency of responses across trials by each participant.

5.5.1.1 Scoring

The phonological similarity effect was measured by comparing the memory spans of both phonologically similar and phonologically dissimilar lists of pictures in serial order.

Children were asked to recall the pictures in serial order. Six trials at each list length were presented, starting with one picture, increasing the list length by one if they were able to complete at least 4/6 trials correctly.

Memory span was measured in two ways: "Span Score" and "Total Trials Correct".

For Span Score, as four correct trials were required to progress or 'pass' that length, the score was the length of the highest list length recalled correctly, with a partial credit given for the next length. As four trials correct was the 'pass' mark, 0.25 credit was given for each correct trial. To calculate Total Trials Correct, the total number of trials recalled correctly in serial order were summed.

Figure 5.3 shows two worked example scores.

- Both children were able to recall a list length of 2 correctly at least 4/6 times, but not a list length of 3.
- Child A passed a list length of 1 and 2 getting 4/6 at each level. At a list of length 3 they recalled only 3 of the 6 trials correctly. Their Span Score is therefore 2.75 (2 being the longest list length where at least 4/6 trials were recalled correctly; and 0.25 credit

allocated for the three trials recalled correctly at a list length of 3.). Their total trials correct is 11 (4 at list length 1; 4 at list length 2; 3 at list length 3)

- Child B passed the first two list lengths with every trial correct, then only one correct at list length 3. Their Span Score is calculated as 2.25 (2 is the longest list length with at least 4/6 trials correct; 0.25 for the one trial correct at list length 3. Total trials correct is 13. (6 at list length 1; 6 at list length 2; 1 at list length 3).

This allows some insight into the performance of each child beyond the overall maximum span length. Children who are 'closer' to achieving the next list length (child A) get credit for this, but also who achieve lists with no errors (child B). It also helps identify differences at very low spans where children are struggling to recall a list length of 1.

Figure 5.3 Examples of span scoring systems

	Child A	Child B
List Length 1	Y Y Y X X Y	Y Y Y Y Y Y
List Length 2	Y X Y X Y Y	Y Y Y Y Y Y
List Length 3	Y Y X X Y X	Y X X X X X
Span Score:	2.75	2.25
Total Trials Correct	11	13

5.5.2 Self-report Strategy Data.

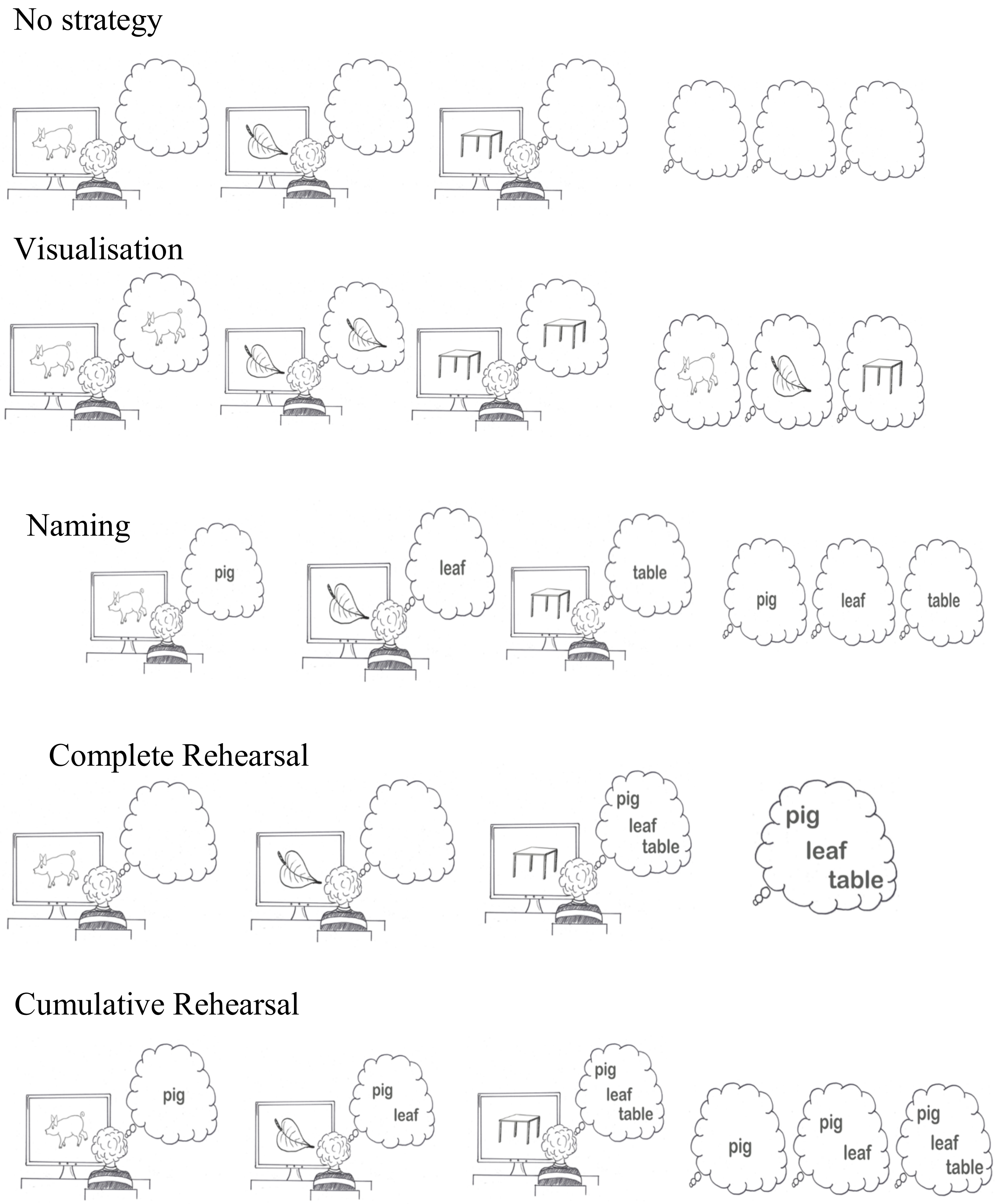
After completion of the original memory task, a second version of the original memory task was administered. This was preceded by an introduction during which the examiner explained five potential memory strategies. These were supported by visual cues on the computer programmed into Gorilla software.

The examiner explained that children could remember things in different ways. These could include doing nothing in particular; visualising the pictures to recall them; naming each picture as it was shown; repeating the names of all the pictures when they had been seen (complete rehearsal); or adding each one to the one prior each time a new picture is seen (cumulative rehearsal). These instructions were accompanied by illustrations, shown on screen in turn (these illustrations are shown in Figure 5.3).

After the explanation and demonstrations of each strategy, children completed two practice trials at list length 2. The same procedure was followed as above for the original tasks but afterwards the child was asked 'how do you remember?' and they then chose the picture (from Figure 5.4) best representing their strategy. They were reminded that if they used more than one, they could choose the one they used most.

After completion of the practice trials, the children completed four lists: phonologically similar and dissimilar (order randomised) at their span capacity, and span +1. Children completed six trials at each length, so twelve in total for each picture type (phonologically similar and phonologically dissimilar).

Figure 5.3 Illustration of different strategies that could be reported after memory task



5.5.3 Related Cognitive Processes

The final part of the session was the administration of five short tasks to record information about other skills that involve the phonological loop or phonological encoding. Each of these areas was selected because of potential overlaps between their underpinning cognitive processes and phonological encoding or working memory more generally, and being of interest clinically. Identification of such relations could help general understanding of both the PSE and these related cognitive processes. Additionally, this understanding may then contribute to understanding of the differences between PSE development in children with DLD and TD.

These were:

- Reaction Time
- Speech rate
- Rapid Automatic Naming (CELF-4 sub-test)
- Word reading (TOWRE-2 sub-test Phonemic Decoding)
- Expressive Vocabulary (CELF-4 sub-test)

5.5.3.1 Reaction Time

This was measured with a simple reaction time task. The children were asked to press a laptop key as soon as a picture appeared to measure reaction time, as well as to make a choice and react as quickly as possible in order to measure reaction time when making a decision. Pictures were programmed to be displayed in different locations on the screen and after different delays from 1-3 seconds. The children responded to 8 pictures and a mean response time was calculated. This assessment was completed using Gorilla programming which records time between presentation and response.

5.5.3.2 Rapid Automatic Naming

The RAN sub-test of the CELF-4-UK (Semel et al., 2006). requires participants to name familiar colours and shapes whilst being timed and taps into processing speed and set shifting as well as working memory. The duration of naming and any errors were recorded for each trial. The RAN is a criterion-referenced test that classifies examinees as being in one of three groups for speed: Normal, Slower than Normal, or Non-normal and for number of errors: Normal, More than Normal, Non-Normal. Decisions consistency between test re-test is reported as 0.87 for time and 0.96 for errors (Semel et al., 2006).

5.5.3.3 Speech Rate

Children were shown a picture on the laptop screen for ten seconds until a visual 'stop' appeared and the examiner also said stop. For the duration the picture was shown, the child was asked to repeat the name of the picture until told to stop. The words tested were four of the phonologically similar lists, and four of the dissimilar lists, presented in a random order rather than blocked for type. The child was recorded and so during playback a time was taken of how long it took the child to repeat the word ten times, and this was averaged over the eight trials to obtain a measure of the children's speech rate. The method was based on that used in previous research (Henry, 1994).

5.5.3.4 Word reading

The Test of Word Reading Efficiency 2 (TOWRE-2) (Torgesen et al., 1999). Phonetic Decoding Efficiency and Sight Words efficiency sub-tests were administered. The child is given 45 seconds to read as many items as possible in a list of 104 words and 63 non-words respectively. The total number of words and non-words read correctly within the time limit was calculated and converted into a standard score. The final total score was used as a measure of reading ability. Reliability coefficients (content sampling) for the subtests exceed .90, demonstrating satisfactory reliability. The average test–retest (time sampling) coefficients for different forms of the subtests is reported as .87 (Torgesen et al., 1999).

5.5.3.5 Expressive Vocabulary

The Expressive Vocabulary (EV) sub-test of the CELF-4-UK (Semel et al., 2006) required children to name pictures of items presented to them. Satisfactory test-retest reliability is reported for this subtest at 0.83 (Semel et al., 2006).

5.6 Planned analyses

The main memory task data will be analysed using a three-way mixed Analysis of Variance (ANOVA) - group (DLD or control) x picture type (phonologically similar or dissimilar) x age (younger or older) - to identify any interaction between group, age and picture type, or main effects of these. This will address RQ1.

It is predicted that the younger control group will show a PSE which increases with age; and that the DLD group may show no PSE at the younger age group with a smaller PSE in the older age group.

To address RQ2, the self-report strategy data will be analysed to identify patterns of any of the strategies over others, and comparisons made between the two groups and age groups using pairwise comparisons.

Finally, regarding RQ3, multiple regression analyses will be performed on the associated processes to identify any predictive value added from reaction time; RAN; speech rate; reading; and expressive vocabulary PSE level.

The following chapters presents the results of the three parts of this study in turn: the calculation of PSE (and therefore detection of phonological encoding) through a memory span task comparing recall of phonologically similar to phonologically dissimilar items; the self-report of which strategies were used to support memory; and the findings from some tasks measuring processes associated with working memory but not previously directly tested in connection with PSE.

The results of each of these will be examined in turn, and the following discussion chapter will interpret the results fully in the context of existing literature.

CHAPTER 6

The PSE in children with DLD

6.1 Introduction

The issue this study aimed to address was whether phonological encoding takes place for children with DLD, and if so whether it does so to a similar extent as for their peers with typical language development. In typically developing children, this process has been repeatedly observed to occur consistently from age 6-7 years, but has, to date, not been investigated in children with DLD. Given the range of difficulties found in children with DLD associated with working memory, particularly phonological working memory, it seems likely that phonological encoding, which requires activation of the phonological loop to convert a visual stimulus into a verbal stimulus retrieved from the phonological store, could be impacted.

It was hypothesised that children with DLD would not show the same level of phonological encoding as their TD peers, and this would be evidenced through no observed PSE in the younger (6-7 years) DLD group, and a smaller PSE in the older (9-10 years) group. As the younger group with DLD are likely to have significantly reduced language ability, including vocabulary, no real difference between recall of phonologically similar or dissimilar picture type is expected, i.e., overall, the younger DLD participants will not demonstrate phonological encoding. In the older DLD group, it was expected that some phonological encoding would be occurring, but that this may not be as extensive as in their peers and may be used concurrently or alternatively with other strategies (e.g., visual memory). As it was not expected that the level of phonological encoding (evidenced by presence of the PSE) observed in the older DLD group would be extensive, it was thought that it might be comparable with typically developing peers of a younger chronological age.

The PSE is widely accepted as a measure of phonological encoding (See section 1.4.1.1) and has been extensively used in research to identify a difference in recall between phonologically similar versus dissimilar pictures, which (if presented non-verbally) must be attributable to internal processes i.e. phonological encoding. However, Jarrold and colleagues have outlined some difficulties around the measurement of the PSE. These authors have argued that the PSE may not always be detected in traditional span tasks, particularly in those with low overall span (Jarrold & Citroën, 2012; Jarrold et al., 2015; Tam et al., 2010; Wang et al., 2016). They propose that traditional calculations which compare recall for similar and dissimilar items do not account for the effect of a low memory performance (i.e., low memory span), which means the PSE is proportionally much smaller in children with lower than in children with larger spans. Therefore, a PSE may be present in those with lower spans, but not detectable through the 'absolute' measures (e.g., the difference in span between a list of phonologically similar and phonologically dissimilar pictures). Instead, Jarrold and colleagues propose use of a 'proportional difference' score, which takes the baseline memory span into account and removes the need to use (possibly misleading) absolute differences between scores. As a result, some suggest the findings of phonological encoding being established in typically developing children around 6-7 years may be misplaced (Tam et al., 2010); that PSE may be present from an earlier age and simply not have been detected in previous studies (Henry et al., 2012), and in fact the PSE simply attributed to a difference observed from the floor effect of low span.

While the current study investigated PSE only in children 6 years and over (i.e., from ages when it is generally accepted that phonological encoding is established), the proportional arguments raised by Jarrold and colleagues are still relevant. This is because children with DLD have been shown to have lower overall span scores than children with TD (Graf Estes et al., 2007). Thus, Jarrold's argument could apply here – i.e., that the group with DLD could demonstrate such low span scores that a PSE may not be detected even if it is present.

In order to counter these arguments, an extra measure of phonological encoding was used in the analyses of the results, that of 'proportional difference' between similar and dissimilar items. The analysis of PSE was calculated using 'Span Scores' and 'Total Trials Correct' (both described in detail in section 5.5.1.1. The Total Trials Correct measure was used in addition to the Span Score as it included slightly more information than the broad strokes Span Score and was therefore considered more sensitive. In addition to these, a 'Proportional Difference' score (as advocated by Jarrold and colleagues) was also calculated. This score was determined by first calculating the 'Absolute Difference' score by subtracting the total number of phonologically dissimilar items recalled from the total recalled of phonologically similar items. This Absolute Difference score was then divided by the score from dissimilar phonological items (i.e., the baseline score) to produce the 'Proportional Difference' score.

These sets of results were used to answer RQ1: Do children with DLD have difficulties with phonological encoding compared to age and non-verbal IQ matched typically developing children?

6.2 Method

To identify the presence of phonological encoding, the phonological similarity effect was measured through comparing the serial recall of phonologically similar words with phonologically dissimilar words. This was done by administering a non-verbal, laptop-based memory game, full details of which can be found in section 5.5.1. Participants were asked to remember a number of pictures that had names that were either phonologically similar or dissimilar. The items were presented visually, and children recalled them by pointing at or clicking on the pictures they had seen in the same order from a matrix of all the possible pictures. Children were asked not to say any of the names out loud, to try to ensure that any phonological encoding processes used would be entirely internal. They completed six trials at each list length, and list length increased by increments of one picture if four out of six trials were selected correctly, as explained in 5.5.1.1. The testing ceased when fewer than 4/6 trials were correct. This procedure was then repeated starting from list length one with the other picture type (the order of phonologically similar and dissimilar picture types was counterbalanced across participants). Performance was scored using two separate methods: span measure, with credit given for partially correct trials, and "total trials correct", the score from every correctly completed trial - see Figure 5.3 for further details and examples of scoring systems. A further measure of Proportional Difference between phonologically similar and dissimilar picture recall was also made.

6.3 Results

Mean memory span scores for each picture type at each age level and group are given in Table. 6.. As expected, on an initial view, the scores for those with DLD were lower than those with TD on both picture types, with scores being lowest for younger children with DLD and highest for older children with TD. There was a greater difference in scores between older and younger groups within the DLD participants than between the age groups of within the group with TD. Normality calculations (which can be found in Appendix D) showed very small deviation from normality in some categories but no significant outliers, and given the majority of results demonstrated normal distributions, and the robustness of ANOVA (Blanca Mena et al., 2017) it was deemed acceptable to proceed with the analyses.

As described above, it was important to consider the potential 'floor effect': the low scores achieved by some of the participants, in particular the younger DLD sample. The mean memory span of the DLD group (shown in Table 6.1) as a whole was 1.78 for phonologically similar and 2.08 for dissimilar – i.e., this group could remember a list of 1-2 pictures. Some of the participants were unable to proceed past a recall 'list' of one item, although 'total trials correct' score allows differences to be seen between the different picture types to some degree, even at lower scoring levels.

Table 6.1 Means and standard deviations (in parentheses) of span score for each picture type for both participant groups at each age levels

	Phonologically Similar	Phonologically Dissimilar
	Mean (SD)	Mean (SD)
All DLD (*n* = 73)	1.78 (0.75)	2.08 (1.01)
All TD (*n* = 59)	2.73 (1.10)	3.43 (1.31)
All 6-7 years (*n* = 69)	1.99 (0.96)	2.44 (1.27)
All 9-10 years (*n* = 63)	2.42 (1.08)	2.92 (1.38)
6-7 years DLD (*n* = 40)	1.58 (0.74)	1.78 (0.80)
6-7 years TD (*n* = 29)	2.64 (0.92)	3.41 (1.18)
9-10 years DLD (*n* = 33)	2.03 (0.71)	2.45 (1.33)
9-10 years TD (*n* = 30)	2.82 (1.26)	3.46 (1.45)

6.4 Statistical Analyses

6.4.1 Span Scores

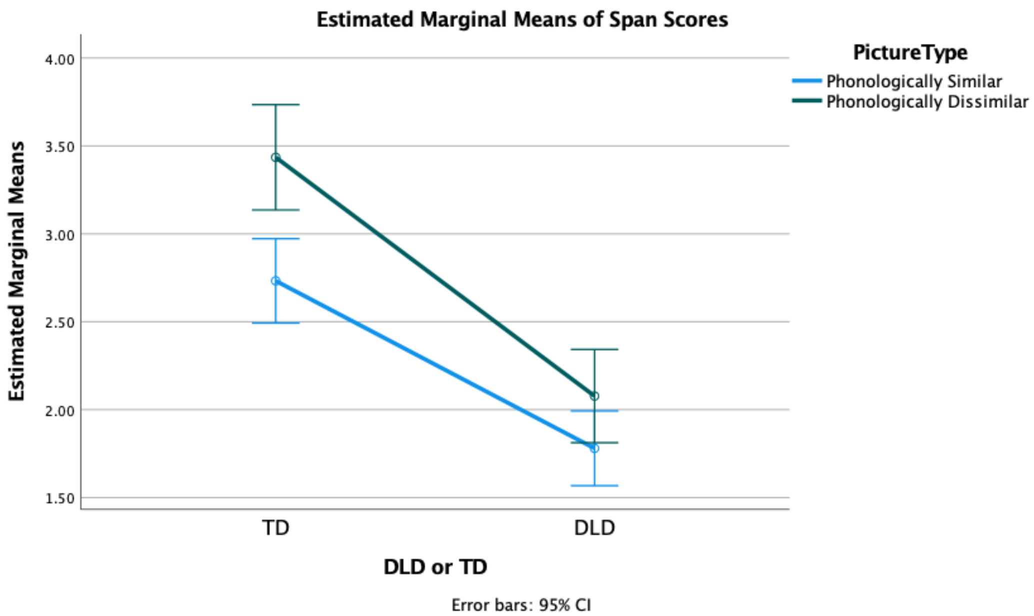
In line with the planned analyses (presented in section 5.6) a 2 x 2 x 2 mixed analysis of variance (ANOVA) was carried out. This included the repeated factor "Picture Type" (dissimilar, similar) and the between-participants factors of "Age" (6-7 years, 9-10 years) and "Group" (DLD, TD) with span scores as the dependant variable.

The results of the ANOVA revealed three main effects in the expected directions. There was a main effect of Picture Type (F (1, 128) = 46.25, p < .001, η_p^2 = .265) with greater recall of phonologically dissimilar than similar pictures (i.e., a significant PSE). There was a main effect of

Group (F (1, 128) = 46.26, $p < .001$, $\eta_p^2 = .266$) with TD children demonstrating greater recall than those with DLD. There also was a main effect of Age (F (1, 128) = 4.11, $p = 0.045$, $\eta_p^2 = .031$), with older children having higher spans than younger children.

Importantly, and pertinently to the original hypothesis, there was a significant interaction of Picture Type x Group (F (1, 128) = 7.05, $p = 0.009$, $\eta_p^2 = .052$) (see Figure 6.1). This demonstrated a difference in recall between picture types in the TD compared to the DLD group: there was a bigger disparity in recall of phonologically similar compared to dissimilar pictures for the TD group than the DLD group (the latter of whom demonstrated much lower overall recall). Post-hoc *t*-tests revealed a significant difference in recall of phonologically similar compared to phonologically dissimilar pictures (i.e., a PSE) for both TD ($t(56) = -6.243$, $p < .001$, $d = 3.97$) and for DLD ($t(72) = -3.43$, $p < .001$, $d = 0.77$) groups. The interaction appeared to be driven by a larger PSE in the TD group.

Figure 6.1 Mean spans of phonologically similar and phonologically dissimilar picture types for each of the TD and DLD groups with standard error bars.



There was no significant interaction of Picture Type x Age (F (1, 128) = 0.090, p = .765, η_p^2 = 0.001), or a three-way interaction of Picture Type x Age x Group (F (1, 128) = 1.31. p = .254, η_p^2 = .01).

6.4.2 Total Trials Correct scores

The analysis was repeated with the 'total trials correct' scoring system. This was based on the total number of trials recalled correctly rather than the summary involving span length. Mean memory scores for total trials correct for each picture type at each age level and group are given in Table 6.2. As with the scores of span length, the youngest DLD group had the lowest scores, and the oldest TD group had the highest scores. Normality calculations (found in Appendix E) showed no significant outliers and only a very small deviation from normality in the older TD group so was robust enough for a parametric ANOVA to be used.

Table 6.2 Mean memory total trials correct (and standard deviations) for each picture type for both participant groups at each age level

	Phonologically Similar	**Phonologically Dissimilar**
	Mean (SD)	**Mean (SD)**
All DLD (*n* = 73)	8.37 (3.62)	10.41 (5.20)
All TD (*n* = 59)	13.50 (5.80)	17.86 (6.66)
All 6-7 years (*n* = 69)	9.80 (5.08)	12.30 (6.21)
All 9-10 years (*n* = 63)	11.54 (5.51)	15.19 (7.42)
6-7 years DLD (*n* = 40)	7.54 (3.65)	8.90 (4.01)
6-7 years TD (*n* = 29)	13.29 (4.95)	17.29 (5.39)
9-10 years DLD (*n* = 33)	9.39 (3.30)	12.27 (5.86)
9-10 years TD (*n* = 30)	13.70 (6.57)	18.40 (7.71)

The above 2 x 2 x 2 mixed ANOVA was repeated, this time using the 'total trials correct' score to measure the effects of Picture Type (within participants factor), Age and Group (between participants factors).

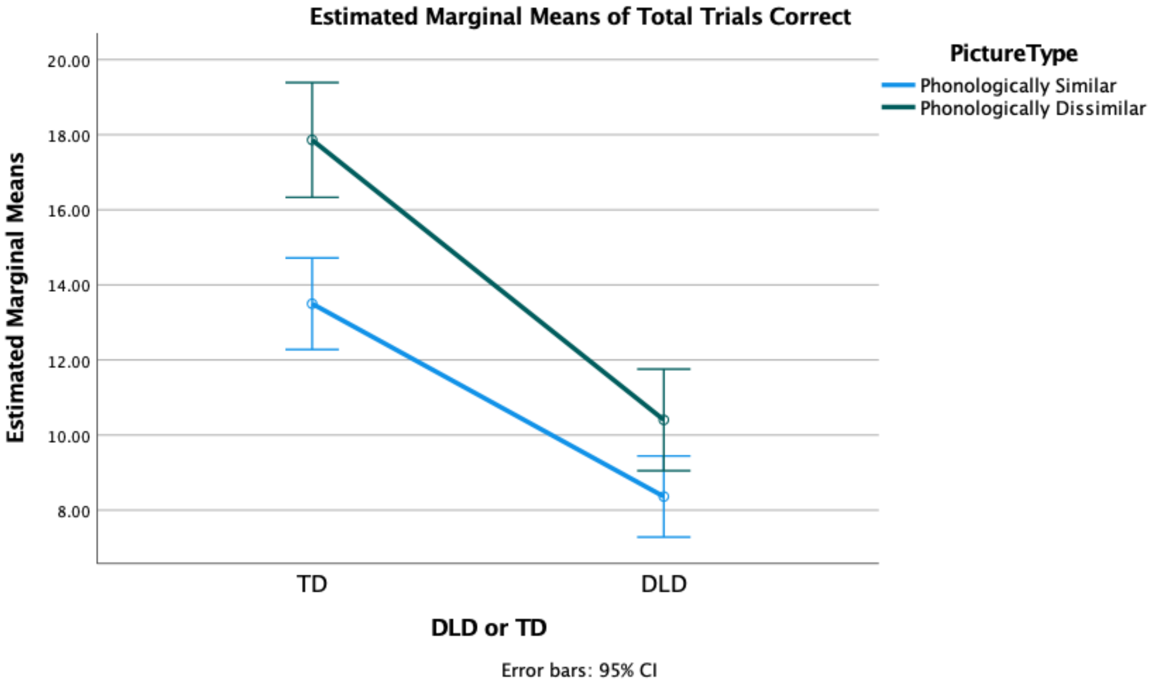
A main effect was found for Picture Type (F (1, 128) = 87.66, p < .001, η_p^2 = .406) with better recall of phonologically dissimilar than similar pictures. There also was a main effect of Group (F (1, 128) = 52.32, p < .001, η_p^2 = .286), TD children scored more highly than those with DLD. The main effect of Age was marginally significant (F (1, 128) = 3.89, p = .052, η_p^2 = .039) with older children showing a tendency to outperform their younger peers.

There was, again, a significant interaction of Picture Type x Group (F (1, 128) = 10.38, p = 0.002, η_p^2 = .075). This demonstrated a difference in recall between picture types in the TD compared to the DLD group: there was a bigger disparity in recall of phonologically similar compared to dissimilar pictures for the TD group than the DLD group (the latter of whom demonstrated lower overall recall). Figure 6.2 illustrates these findings, which are consistent with the hypothesis made above that there would be a larger PSE for TD children.

There was no interaction of Picture Type x Age (F (1, 128) = 2.56, p = .112, η_p^2 = 0.02), or a three-way interaction of Picture Type x Age x Group (F (1, 128) = 0.35, p = .558, η_p^2 = .003). Consequently, there was no support for the hypothesis that there would be a significant difference in PSE by Age, or that younger children with DLD would not demonstrate a PSE.

These findings are consistent with those from the span scores – the TD group demonstrated a bigger difference between recall of the phonologically dissimilar compared to similar pictures than the DLD group. There was a small significant difference for Age using span scores that missed significance with Total Trials correct.

Figure 6.2 Mean trials correct of phonologically similar and phonologically dissimilar picture types by each of the TD and DLD groups with standard error bars.



To further investigate the Picture Type by Group interaction, post-hoc tests were carried out to identify where the differences were located. A paired sample *t*-test was used to investigate the difference between total trials correct of phonologically similar vs phonologically dissimilar pictures (e.g., whether a PSE is present). This revealed a significant difference between recall in the DLD group: $t(73) = -4.66$, $p < .001$, $d = 3.76$ and the TD group: $t(57) = -7.96$, $p < .001$, $d = 4.17$ indicating the presence of a PSE in both groups with large effect sizes.

As both groups demonstrated a PSE this suggests that the source of the significant observed interaction was due to the size of the PSE – the TD children had a bigger PSE, and a larger difference in recall between phonologically similar and dissimilar pictures, than children with

DLD. The latter do show poorer performance in recall of phonologically similar pictures but not to the same extent as their TD peers.

6.4.3 Proportional Differences Scores

Normality calculations showed that the proportional difference scores for the TD group were significantly non-normal (*W* (58) = .150, *p* = .002) and identified one outlier (participant H6). The DLD group scores were also non-normally distributed (*w* (74) = .846, p <.001) with one outlier (participant D4). The results showed some extreme skewness and kurtosis (see Appendix F). Removing the outliers lying beyond 2 standard deviations from the mean resulted in a more normal distribution and analyses continued with these – scores excluding the outliers are shown in Table 6.3, which shows that the TD group appear to have twice the proportional difference score for PSE than the DLD group overall, with little obvious difference between age groups.

Table 6.3 Means and standard deviations for absolute and proportional difference scores (excluding two outliers)

	Absolute Difference Score	**Proportional Difference Score**
	Mean (SD)	Mean (SD)
All DLD (*n* = 72)	2.10 (3.76)	0.11 (0.39)
All TD (*n* = 58)	4.54 (3.97)	0.24 (0.22)
All 6-7 years (*n* = 67)	2.63 (3.73)	0.16 (0.35)
All 9-10 years (*n* = 63)	3.75 (4.28)	0.18 (0.31)
6-7 years DLD (*n* = 39)	1.45 (2.96)	0.10 (0.41)
6-7 years TD (*n* = 28)	4.37 (4.11)	0.24 (0.21)
9-10 years DLD (*n* = 33)	2.88 (4.46)	0.12 (0.36)
9-10 years TD (*n* = 30)	4.70 (3.91)	0.24 (0.23)

Two 2 x 2 ANOVAs (two between-participant factors: ‘Age’ and ‘Group’) were carried out using: (a) the absolute difference scores between similar and dissimilar items; and (b) proportional difference scores. These measures were based on the total trials correct scores (minus the two outliers). Absolute difference scores were calculated and included for completeness, to allow comparison of the different calculations of PSE. Proportional difference measures (as opposed to the above span / total trials correct measures) are combined into one single ‘difference’ measure.

For (a) absolute difference scores, there was a main effect of group with higher difference scores in the TD group (F (1, 129) = 12.11, p = <.001, ηp2 = .088) (Figure 6.3). However, there was no significant effect of Age (F (1, 129) = 1.66, p = .199, ηp2 = .013). There was no interaction of Group and Age (F (1, 129) = .651, p = .421, ηp2 = .005).

For (b) proportional difference scores, there was a main effect of group (F (1, 125) = 4.94, p = .028, ηp2 = .038) with higher difference scores in the TD group (Figure 6.4). However, there was no significant effect of Age (F (1, 125) = 0.012, p = .914, ηp2 = .000). There was no interaction of Group and Age (F (1, 125) = 0.028, p = .866, ηp2 = .000).

These analyses show that even when accounting for a difference in baseline memory span, there is still a significant difference in the size of the PSE between groups. This confirms the earlier findings demonstrating a group effect for recall of different picture types – typically developing children have a significantly higher PSE than children with DLD.

Figure 6.3 Mean of absolute difference total trial scores of TD and DLD groups

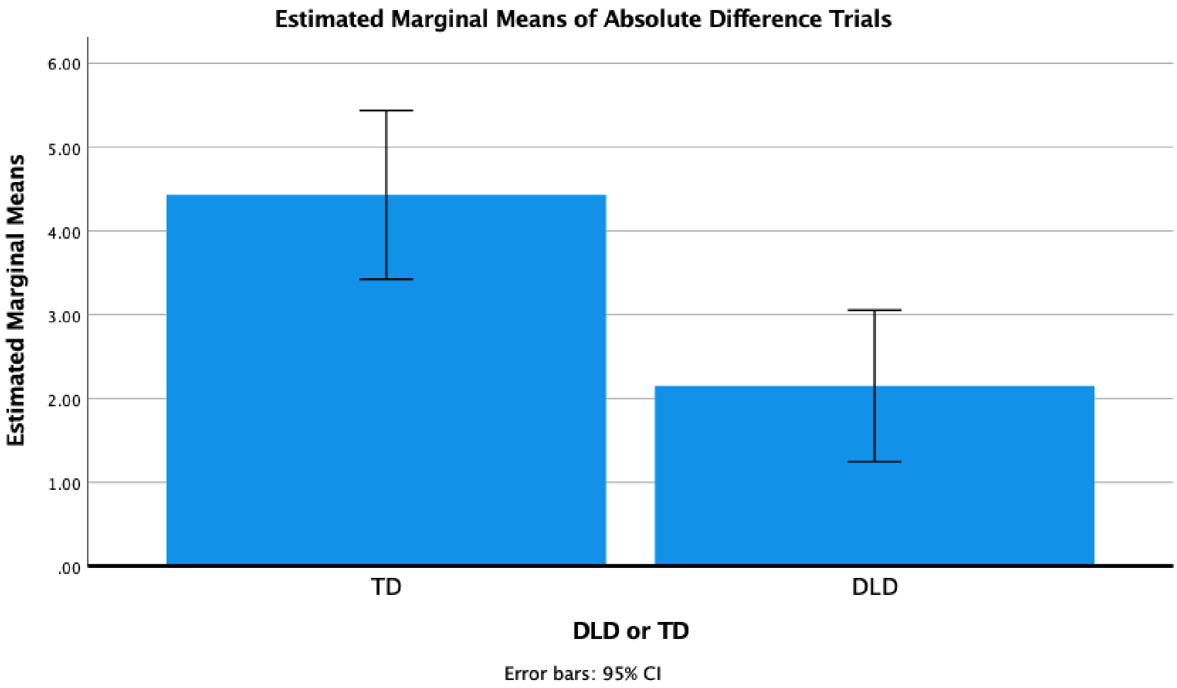
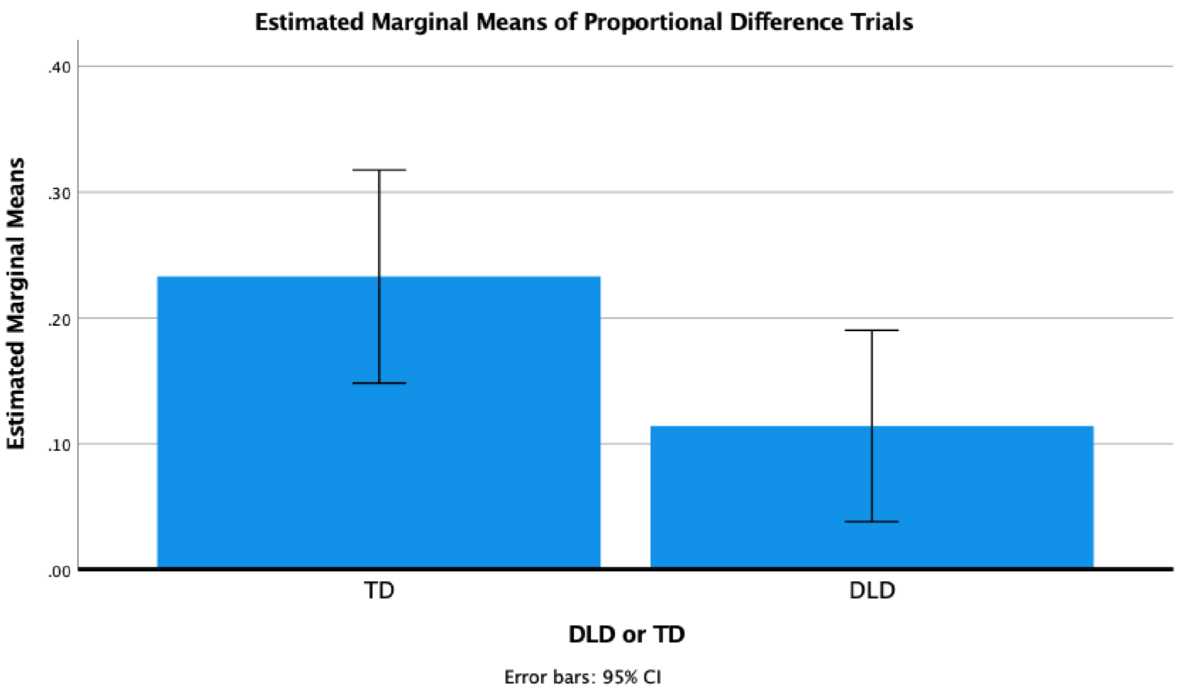


Figure 6.4 Mean of proportional difference total trial scores of TD and DLD groups



There was no difference found in absolute or proportional difference scores between the two age groups, nor was there an interaction between group and age. The PSE was significantly smaller for the DLD group even when the scoring method compensated for their lower baseline recall, which contributes to a strong confirmation of the original hypothesis made in response to RQ1: there is a more fundamental difference in phonological encoding, that goes beyond baseline memory span level, between those with typical language and those with DLD.

6.5 Discussion

The present investigation adds to the knowledge base about the development of phonological encoding in children with DLD between the ages of 6-10 years, through analysis of the phonological similarity effect. By considering the level of recall of phonologically similar compared to phonologically dissimilar pictures, when the material to be recalled is visually presented, and recall method is non-verbal, it is possible to consider whether phonological encoding is occurring. This is done by considering whether differences in recall of these picture types emerge due to participants being affected by how words 'sound' through activation of the phonological loop.

The analyses in the current chapter provide evidence that, as predicted, there is a significant difference in the size of the PSE, and therefore use of phonological encoding, between children with and without DLD. Using scores obtained from the recall of phonologically similar and phonologically dissimilar pictures, this was demonstrated consistently with several methods: span scores; total trials correct; absolute difference scores; and proportional difference scores.

As expected, the performance on the memory task of TD children outstripped their DLD peers (Henry, 2011; Jackson et al., 2021; Larson & Ellis Weismer, 2022), with a significant group difference between the recall scores of phonologically similar compared to dissimilar items. In line with previous findings (Henry et al., 2012) a PSE was detected in typically developing children in both age groups. A PSE was also found in both DLD age groups. This was surprising, as it had been expected that no PSE would be observed in the younger DLD group due to the impact of DLD on their language abilities, for example restricted vocabulary, resulting in a delay in the development of use of phonological encoding. This suggests that children with DLD do not suffer a 'simple' delay: their performance was not equivalent to younger TD peers and a PSE appeared to be present (although it was to a lesser extent than those with TD).

Use of a 'proportional measure' of the PSE did not remove the differences between the groups. (Jarrold et al., 2015) have proposed that the PSE is proportional to recall level, and therefore with lower overall recall levels there is a smaller PSE, or indeed a PSE so small that it may simply be undetected at low span levels. Thus, apparent differences between groups (usually differences between different age groups, especially when young children with low spans are included) in the size of the PSE could be spurious. The DLD group in the present study did demonstrate significantly lower overall span/recall levels that those in the TD group, but the differences in the size of PSE between the groups were still present when using absolute or proportional difference measures. Thus, this suggests that there is a 'real' difference between these groups in the extent to which they use phonological encoding. Jarrold and colleagues do state a caveat to their position, which is that proportional scoring may only work from a minimum threshold level of performance. This was considered carefully for the current study – but given the overlap in scores between some of the lower performing children in the TD group and the higher performing children in the DLD group, this does not seem to be applicable to the current findings.

These results suggest that in the DLD group there is less 'similarity' disruption occurring due to phonological encoding when attempting to recall pictures with phonologically similar names. A fundamental difference in phonological short-term memory may be responsible for this difference, in that children with DLD may use a different strategy to support recall or lack the ability to phonologically encode in the same way as TD children, which in turn limits new vocabulary learning and impacts working memory further. This cycle of difficulty could be one of the causes of DLD and will be explored in greater detail in chapter 9.

In response to RQ1 (Do children with DLD have difficulties to phonological encoding compared to age and non-verbal IQ matched typically developing children?) we can conclude that children with DLD do appear to have a significant reduction in their use of PSE and phonological encoding compared to their TD peers. Strengthening this finding is the fact that this result was consistent across different measures of assessing "span" performance, using either traditional 'span' measures or measure of total trials correct; it was also consistent when absolute and proportional difference scores were used.

The significant difference in size of PSE between children with DLD and those with TD suggests a fundamental difference in the operation of phonological encoding and its use by these groups in short-term working memory tasks. One theory is that of Siegler's 'overlapping waves' of development: that as a new skill is learned, it is gradually practised and implemented (McGilly & Siegler, 1989). A strategy that is more complex is not necessarily immediately more effective as it can use more resources (e.g., more attention, taking away from working memory capacity), so in the short term can reduce performance in the skill it aims to support. Strategies that are 'simpler' continue in usage alongside the new strategy, and in this way simpler strategies continue to improve performance while newer skills are honed.

It could be that children with DLD are not at the same stage of 'expertise' in phonological encoding and so it is not used as consistently as their TD peers, resulting in the smaller PSE due to reliance on alternate 'simpler' recall methods during the memory task (such as visual memory, for example). It is also known that children with DLD have poorer phonological awareness, and weaker phonological representation in long-term memory (Jones, S. & Westermann, 2021). As a result, despite some level of phonological encoding occurring to activate the representation in their phonological loop, it may be not as focussed as it would be in those with TD who are, therefore, more sensitive to the overlap in phonological qualities in the word list of the similar items and therefore suffer more disruption.

Strongly linked to phonological encoding is the process of verbal rehearsal, a strategy that can be conscious or unconscious and involves 'reciting' to-be-remembered words to keep them current and active in the phonological loop for recall. This may increase the impact of the phonological similarity effect, due to the repetition. An increased use of rehearsal could therefore be associated with an increased PSE. The next chapter will explore whether differences in this area could further explain the observed disparity in PSE and attempt to identify causes of the difference in children with DLD.

CHAPTER 7

Self-report of strategy use in children with DLD

7.1 Introduction

The second issue explored in this thesis was that of strategy use in phonological short-term working memory tasks, specifically those involving verbal rehearsal and verbal naming strategies. Various types of naming and verbal rehearsal strategies have been identified in previous investigations, including simple naming or labelling ('saying' the name of the stimulus once it is presented), complete rehearsal (repeating the names of all the to be remembered stimuli once they have been presented) and cumulative rehearsal (naming each picture and repeating and adding each new picture name to this list). All of these can occur overtly (out loud) or internally ('in one's head').

It is important to emphasise that verbal naming and rehearsal can occur after phonological encoding, if a visual stimulus is being presented to be remembered, and it is presented non-verbally. Rehearsal strategies can also be implemented without the process of phonological encoding, if the to-be-recalled items are presented with additional verbal labels at presentation (because the phonological representation is then activated within the phonological loop directly). The current study was concerned only with non-verbal presentation, e.g., the participant is presumed to first have carried out phonological encoding, before engaging in any naming and/or verbal rehearsal strategies.

Previous work has demonstrated that naming and/or verbal rehearsal appears to emerge around age 6-7 years and develops over the primary years, with cumulative rehearsal more commonly used by age 10, in typically developing children (Henry et al., 2012; Hulme et al., 1984; Poloczek et al., 2019). Knowing that previous studies looking at children with DLD have found a delay in related areas such as self-directed speech (Abdul Aziz et al., 2017; Lidstone et al., 2010; Sturn & Johnston, 1999); as well as the known working memory difficulties in this population and the demonstrated difference in use of phonological encoding (see section 2.3), it was hypothesised that there would be a different developmental pattern of naming and verbal rehearsal strategies in children with DLD compared to their TD peers, with a greater proportion using non-verbal (no strategy or visual rehearsal) or simple verbal strategies such as naming, compared to their peers using cumulative rehearsal.

Cumulative rehearsal is the most 'complex' of the verbal strategies, requiring considerable attentional and working memory capacity in order to both hold an increasing list length in mind and rehearse. This strategy appears to develop at a later age and stage than simple naming, for example, and may possibly have a detrimental effect on memory span while it is first being 'honed', as it could divert resources from working memory to the strategy process. It may also take practice before cumulative verbal rehearsal becomes a more efficient and 'preferred' strategy (Lehmann & Hasselhorn, 2007). These authors found that it was not observed at all until over 7 years and suggest this was because working memory capacity was not sufficient to support it.

Of course, participants may not use any verbal strategies – some children have reported visual rehearsal strategies, that appears to involve representing the picture in their mind without labelling it, or using 'no' strategy (Poloczek et al., 2013). Furthermore, if the children did not carry out phonological encoding, then it seems unlikely that they would be able to use any verbal rehearsal strategies. As the children with DLD appear to carry out phonological encoding to a lesser degree than TD peers (as discussed in Chapter 6) then this would suggest that the children with DLD are less likely to use a verbal-based rehearsal strategy.

This chapter therefore considers the self-report data collected from each participant regarding which, if any, strategy they used to support their performance in the memory task, in order to answer RQ2:

- Does the development of verbal strategies follow the same pattern in children with DLD between 6 and 10 years as their age and non-verbal IQ matched typically developing peers?

7.2 Method

As described in section 5.5.2, for this task, participants completed the same phonological short-term memory serial recall tests as they had completed previously: children were shown pictures on a laptop one at a time and then asked to select, from a matrix of pictures, which ones they had seen, in the same order that the pictures had been presented. After each trial, the children were then prompted to select which strategy they had used to help them remember, with options of 'nothing', 'visual' 'naming' 'complete' or 'cumulative' rehearsal with picture support (shown in Figure 5.4) to help them understand these options. If they reported using more than one strategy in a trial, they were encouraged to choose the one they used 'most'. Before commencing the task, the concept of using 'remembering' strategies and an example of each was given was introduced, with visual supports shown on screen. The researcher explained each strategy using the visual support and gave the children an opportunity for questions. Three practice trials were administered at a list length of two items for all participants, with the strategy question asked after each trial.

The whole task was completed at two list lengths for each picture type: for each child the span length (calculated from highest number of items recalled correctly in the previous task) and at one above the child's span (span+1). These spans were calculated for phonologically similar and dissimilar pictures separately (i.e., if a participant's highest span scores in the memory tasks was 2 for phonologically similar pictures and 3 for phonological dissimilar items, they would be presented with phonologically similar lists of pictures at list lengths 2 and 3; and phonologically dissimilar lists of pictures at list lengths 3 and 4). Six trials were presented at each list length. This provided 12 data points to obtain strategy choice self-report data for each picture type. (e.g., six at span, six at span+1 for phonologically similar pictures; the same for phonologically dissimilar pictures).

Participants were reminded not to speak when pictures were presented or when giving their responses to ensure that this task was presented in the same way as it had been for Chapter 6. This ensured the recall method was also non-verbal –and participants were reminded not to speak aloud in the initial instructions, and, again, if they were observed to speak aloud during the task. As a result, if any verbal strategies were used, they would have to have been internalised.

This chapter considers self-reported data about verbal strategy use. Responses were collected via the participants' own reporting after each individual trial.

7.3 Results

In order to analyse the data, the number of times each child selected a strategy was calculated, this was then converted to a percentage (i.e., total for a strategy/12 x 100). The mean percentage scores are shown in Table 7.1 and Table 7.2. From these we can see that all the strategies were chosen by some children across both picture types. Although there were differences in the means between the picture types, and between the age groups, the standard deviations suggested that the distributions for these percentages overlapped. In contrast, there were larger differences between DLD and TD groups for the different strategies.

Table 7.1 Means and standard deviations for strategy choices reported for phonologically dissimilar picture recall

	Naming Mean (SD)	Cumulative Mean (SD)	Complete Mean (SD)	Visual Mean (SD)	Nothing Mean (SD)
All DLD (*n* = 73)	23.47 (24.25)	22.41 (27.58)	11.41 (10.45)	19.36 (19.89)	23.32 (25.77)
All TD (*n* = 59)	25.95 (22.85)	35.62 (29.03)	8.67 (9.79)	11.79 (11.07)	17.88 (21.95)
All 6-7 years (*n* = 69)	23.77 (23.33)	26.71 (27.99)	10.06 (10.78)	17.62 (19.43)	21.75 (24.90)
All 9-10 years (*n* = 63)	25.43 (24.03)	29.86 (29.96)	10.37 (9.64)	14.30 (11.97)	20.03 (23.64)
6-7 years DLD (*n* = 40)	20.59 (22.96)	22.61 (27.81)	11.93 (10.76)	22.12 (22.26)	22.76 (24.71)
6-7 years TD (*n* = 28)	28.43 (23.48)	32.71 (27.64)	7.32 (10.40)	11.04 (11.85)	20.29 (25.57)
9-10 years DLD (*n* = 33)	27.06 (25.66)	22.15 (27.71)	10.76 (10.18)	15.94 (13.15)	24.03 (27.41)
9-10 years TD (*n* = 30)	23.63 (22.40)	38.33 (30.49)	9.93 (9.18)	12.50 (10.45)	15.63 (18.10)

Table 7.2 Means and standard deviations for strategy choices reported for phonologically similar picture recall

	Naming Mean (SD)	Cumulative Mean (SD)	Complete Mean (SD)	Visual Mean (SD)	Nothing Mean (SD)
All DLD (*n* = 73)	24.85 (26.39)	16.14 (18.98)	13.64 (13.90)	24.84 (22.49)	20.47 (24.41)
All TD (*n* = 59)	21.17 (18.54)	29.57 (19.98)	10.17 (12.81)	25.12 (26.16)	17.02 (18.23)
All 6-7 years (*n* = 69)	21.10 (21.52)	18.25 (18.34)	13.75 (13.92)	26.52 (22.62)	20.29 (22.49)
All 9-10 years (*n* = 63)	25.57 (24.99)	23.43 (21.57)	10.32 (12.88)	23.25 (25.65)	17.49 (21.31)
6-7 years DLD (*n* = 40)	21.10 (23.50)	13.83 (17.45)	14.02 (13.98)	27.83 (23.39)	23.15 (26.33)
6-7 years TD (*n* = 28)	21.11 (18.66)	24.71 (17.97)	13.36 (14.07)	24.61 (21.71)	16.11 (14.72)
9-10 years DLD (*n* = 33)	29.52 (29.29)	19.00 (20.64)	13.15 (13.99)	21.12 (21.08)	17.15 (21.73)
9-10 years TD (*n* = 30)	21.23 (18.74)	28.30 (21.85)	7.20 (10.93)	25.60 (30.09)	17.87 (21.21)

Analyses were run to see if there were any significant differences between the groups and within group differences (e.g., whether any one strategy was selected significantly more frequently than another).

Initial analyses showed no significant difference between strategy selection for phonologically similar compared to dissimilar picture types (full results can be found in Appendix G) nor between age groups (i.e., no significant differences were shown in strategy selection between the younger and older DLD groups or younger and older TD groups – full results can be found in Appendix H). Consequently, the data were collapsed for Picture Type and Age, and analyses proceeded comparing DLD and TD participants (Table 7.3).

Table 7.3 Means and standard deviations for strategy choices reported for picture types combined

	Naming Mean (SD)	**Cumulative Mean (SD)**	**Complete Mean (SD)**	**Visual Mean (SD)**	**Nothing Mean (SD)**
All DLD (*n* = 73)	24.32 (23.46)	19.26 (19.43)	12.62 (9.88)	22.12 (17.39)	21.97 (21.98)
All TD (*n* = 59)	23.37 (14.84)	31.08 (19.95)	9.51 (8.88)	18.69 (13.30)	17.49 (15.74)

7.4 Statistical Analyses of Strategy Choice by Group

The data were non-normally distributed and so non-parametric independent samples tests (Mann-Witney *U*) were performed to compare the frequency of selection of each strategy between the TD and DLD groups (Table 7.4). Five Mann-Whitney *U* tests were performed, one for each type of strategy. This revealed statistically significant differences between the TD and DLD groups, with the TD group choosing Cumulative rehearsal more frequently (Mean rank 80.19) than the DLD group (mean rank 55.43) ($p < .001$); and the DLD group choosing Complete rehearsal more frequently than the TD group (mean rank 72.45; TD mean rank 59.14) ($p = .044$).

Table 7.4 Results of Mann-Witney test comparing strategy selection between TD and DLD groups

	N = 132	
Strategy	***U***	***p***
No strategy	2355.5	.353
Visual rehearsal	2376.5	.305
Naming	1968	.394
Complete rehearsal	2587.5	**.044**
Cumulative rehearsal	1345.5	**<.001**

A Friedman test of related samples (a non-parametric equivalent of one-way ANOVA) was then carried out within each clinical group separately to identify if there were significant differences in strategy selection within each group, comparing each choice of each strategy to another.

There was a statistically significant difference found in the selection of the strategies in both groups (TD, $\chi^2(4) = 44.25$, $p < .001$; DLD $\chi^2(4) = 14.04$, $p = .007$).

Post-hoc comparisons were then made to investigate these specific significant differences using Wilcoxon paired samples tests to identify their location. Results can be seen in Table 7.5.

These pairwise comparisons showed that for both groups, complete rehearsal was chosen significantly less frequently than any other strategy. For the DLD group there was no other significant differences between the five strategies. In contrast, for the TD group, there were several significant differences in the percentages. Cumulative rehearsal was selected significantly more frequently than any other strategy, bar naming. Furthermore, naming was reported significantly more often than no strategy (and complete rehearsal). This suggests the TD group used the two verbal strategies of Cumulative rehearsal and Naming significantly more overall than a non-verbal (visual) strategy or no strategy.

The DLD group did not report the 'complete' rehearsal strategy as often, but otherwise did not show a difference between their choice of any of the other four strategies, either the verbal, non-verbal or no strategy options.

Table 7.5 Results of Wilcoxon statistics comparing pairwise strategies chosen by each group

TD \ DLD	**None**	**Visual**	**Naming**	**Complete**	**Cumulative**
None		$W = 1305$, $p = .419$	$W = 1131.50$, $p = .649$	$**W = 1517.5$, $p = .004$	$W = 1245$, $p = .660$
Visual	$w = 658.5$, $p = .839$		$W = 1128.5$, $p = .883$	$***W = 1602$, $p < .001$	$W = 139.11$, $p = .244$
Naming	$*W = 380$, $p = .033$	$W = 531$, $p = .150$		$**W = 617.5$, $p = .002$	$W = 658$, $p = .180$
Complete	$**w = 786.5$, $p = .007$	$***w = 1097$, $p < .001$	$***w = 189.5$, $p < .001$		$*W = 618$, $p = .029$
Cumulative	$***W = 450$, $p = .003$	$***W = 367$, $p = .001$	$W = 1094.5$, $p = .064$	$***W = 74.5$, $p < .001$	

$*p \leq .05$; $**\ p \leq .01$; $***\ p \leq .005$

7.5 Discussion

This chapter has looked at the self-reported use of verbal strategies in children with DLD when asked to serially recall lists of nameable pictures within phonological short-term memory tasks.

The findings contribute to the knowledge base concerning how naming and verbal rehearsal strategies develop and are used by those with language and working memory difficulties. By collecting data on self-reported strategies used to support recall, differences between children with DLD and their TD peers were identified: children with DLD reported using cumulative rehearsal (the most 'advanced' verbal rehearsal strategy, and arguably the most complex option) significantly less often than children with typical language of the same age. These findings were in line with the hypothesis that children with DLD will demonstrate a difference in the development of memory strategies. The findings from the current chapter also dovetail with the findings from Chapter 6, that children with DLD demonstrate a significantly smaller PSE (hence, less phonological encoding) than those without DLD.

In order to use verbal strategies, in this context of a serial short-term memory task that presents nameable pictures, children must first be able to phonologically encode the visual stimuli. As this appears to be occurring to a lesser extent in children with DLD, it makes sense that verbal rehearsal is also used less frequently. In addition, we might expect that if a child uses verbal rehearsal, the increased verbal repetition of the verbal labels of the items to be remembered will increase the PSE, as the increase in repetitions means there are more opportunities for error which are then rehearsed and repeated causing the confusion in recall.

If phonological encoding has occurred, different levels of "verbal strategies' may then be implemented. For example: the simple act of labelling the object with name (internally) as it is presented (known here as 'naming'); reciting (internally) all the names of the items after presentation of full list ('complete' rehearsal); or naming each item in turn and repeating it and adding on the name of the next item as it is presented ('cumulative' rehearsal). These are listed here in the generally accepted order of 'complexity' and developmental order of acquisition. However, it should be noted that previous work has identified that multiple strategies may be used within one recall task, e.g., cumulative rehearsal for first 2-3 items, no strategy for 4th, and then simple naming for 5th (McGilly & Siegler, 1989; Poloczek et al., 2019).

Previous work has revealed that the use of verbal rehearsal develops over childhood and is highly associated with executive function and performance on a variety of working memory tasks (Tam et al., 2010). Interestingly, the phonological similarity of the picture lists did not affect self-reported strategy results in this sample: children chose the same types of strategies regardless of picture type. This appears to suggest that the children were either unaware that there were two types of lists, or if they were aware of the two types of lists they did not alter their strategy in relation to this knowledge. In addition, no developmental differences were seen between the age groups, with the younger groups of 6–7-year-olds choosing strategies with similar frequency to their 9–10-year-old counterparts. This appears to suggest that there was no large change in strategy selection over this age range, although further research is needed before this conclusion is accepted.

Both language groups had a low percentage of 'complete' (or 'once through') rehearsal - this was selected significantly less often than any other strategy. The TD group also chose 'no strategy' significantly less often than naming or visual strategies. Except for complete rehearsal, the DLD group did not report any other strategy significantly more often than any other. It could be that children with DLD are less able to choose an appropriate strategy for the task or identify the most effective strategy in that moment. It seems likely that, compared to TD peers, children with DLD are at an earlier stage of the 'overlapping waves' theory of strategy development. It has also been shown that during the development and acquisition of new skills – for example, cumulative rehearsal – children may suffer detrimental effects on their performance, as they hone and refine a new skill (Al-Namlah et al., 2006).

It was demonstrated in the current chapter that rehearsal strategies were not reported consistently, or uniformly, by children with or without DLD, beyond an increased frequency in the TD group in selection of cumulative rehearsal. All the other options were also reported to be used at times as well. There are no significant differences between younger (aged 6-7) and older (9-10 year) participants with respect to which strategies were reported, suggesting the development of these strategies is fluid, individual, gradual, and adaptive to the task in hand. Perhaps due to the way strategies were reported in this task and the way memory was measured (e.g., serial immediate recall rather than free recall; non-verbal self-report from a finite selection) the findings differed from previous research. For example, Lemaire and Siegler (1995) investigated which strategies were reported in the same memory task at three different time points over a year. They found the same strategies were reported, but there was a difference in the proportion of each strategy being reported over this age period (7-8 years). Over time, the reported use of cumulative rehearsal increased above that of naming.

Cumulative rehearsal also requires more working memory capacity and general cognitive power. Children must record the items into a set, so this strategy can only be utilised when recalling lists of more than one item, yet some children in the DLD group had a span length of only one item. It therefore follows that these children would not technically be able to use cumulative rehearsal (although it should be noted that there was no control for the self-report aspect of whether this option was 'possible', and it was observed that some children chose 'cumulative' even after a trial with only one item in the list.)

Another important factor in acquiring different verbal strategies includes learning in which situation to use which strategy. In free recall tasks, it has been observed that children would prioritise e.g., for digit recall if the numbers were sequential, they did not rehearse, but for random numbers they would, because of the higher memory capacity required to recall random lists (McGilly & Siegler, 1989). It would be interesting to consider whether those children that reported cumulative rehearsal within the DLD group tended to have a larger PSE, or whether the emergent aspect of applying a new and complex strategy meant that the additional resources required compromised performance on the memory span task. Overall, it seems likely that a variety of verbal strategies continue to be used depending on task demands until and even through to adulthood, as demonstrated within the TD group, but that these strategies are developed to become more efficient and selected more carefully for specific task demands.

The findings in relation to self-reported strategies corroborate the findings in section 6.3. Specifically, there was a difference in the self-report of a specific verbal strategy – cumulative rehearsal - which was reported more frequently in children with TD than in children with DLD. This pattern of increased self-report of cumulative rehearsal within the TD group dovetails with the greater PSE observed in the children with TD in Chapter 6. Cumulative rehearsal requires verbal repetitions of the to-be-remembered list and, thus, is likely to increase the risk of error in terms of phonological confusion in serial order recall.

The differences between the self-reported strategies in the two clinical groups found in this chapter, combined with the findings of the previous chapter, suggest there are important differences in phonological short-term memory development between children with and without DLD. The next chapter aims to identify if these differences are related to performance in any other tasks that overlap with respect to the cognitive processes involved.

As a result of this background, the current study aimed to develop further understanding of the development of rehearsal strategy use. From the literature, we expected to see more cumulative rehearsal strategies reported by older participants, and potentially only in older participants with higher vocabulary scores. Rather than a qualitative jump, it also seemed likely that an overlap of simpler (naming) and more complex (rehearsal) verbal strategies being used concurrently between and even within trials would be observed (Poloczek et al., 2013). However, it is unclear whether the use of cumulative rehearsal improves memory span; or if memory capacity limits cumulative rehearsal use (Jarrold & Hall, 2013). Strategy choice may relate to memory span broadly, in that those with lower memory span may be more likely to use a naming method, and those with higher spans cumulative rehearsal. As a result of this it seems plausible that children with DLD may use different memory strategies to age matched peers – because of their lower vocabulary scores and lower memory spans.

CHAPTER 8

The Prediction of PSE from Related Cognitive Processes

8.1 Introduction

The final area explored in the current thesis was that of investigating associations between the PSE and other key abilities known to be related to working memory: reaction time, speech rate, reading, expressive vocabulary and rapid automatic naming. Each of these areas was selected because of potential overlaps between their underpinning cognitive processes and phonological encoding (or working memory more generally). It is hypothesised that they each involve the same underlying mechanisms involved in phonological encoding, as well as being of relevance in clinical practice. Identification of such relations could help general understanding of both the PSE and these related cognitive processes. Additionally, this understanding may then contribute to understanding of the differences between PSE development in children with DLD and TD.

Reaction time and Rapid Automatic Naming (RAN) both involve processing speed, which is key to working memory (Fry & Hale, 2000). Given the known links between DLD and reduced working memory capacity, detailed in section 2.2, it is hypothesised that corresponding reductions in reaction time and RAN will be observed in this group. Further, developmental increases in working memory correlate with increases in processing speed (Bayliss et al., 2005). As working memory involves the holding in mind of information while a cognitive task is carried out, it is logical that increased processing speed therefore improves working memory. Mapping onto Baddeley's working memory model, this could be explained by the increased opportunity for larger rehearsal sets with increased processing speed. Being able to identify words faster; process and rehearse to-be-remembered items quicker and more efficiently also means the items to be remembered are less likely to have faded (Fry & Hale, 2000). Further, the quicker one is to respond to a stimulus (reaction time) the more rehearsal time is available, and the longer is available for encoding before the next item is presented. Related to this line of argument is the suggestion that children with DLD have more limited working memory capacity which means that they have fewer resources to support processing which may, in turn, be slower (Marton & Schwartz, 2003). Rapid Automatic Naming is another complex task requiring processing speed. It involves the sequential naming of a limited set of visually presented items as quickly as possible. The task is likely to involve the rapid processing of information. Therefore, there are good reasons to expect that processing speed (reaction time and RAN) will both be related to the PSE.

Speech rate is another related measure, which is hypothesised to correlate with phonological encoding and verbal rehearsal, as repetition in the phonological loop is thought to occur in real time (Hulme et al., 1984). Those with faster rates of 'speech' can use verbal rehearsal much faster. There are mixed opinions from previous research on whether speech rate differs in children with DLD. While some have found that there was no group difference (Montgomery, 1995) others have found a significant difference favouring typical children (Hasselhorn & Grube, 2003). It was therefore considered useful to include a measure of speech rate to see if there was a difference between children with DLD and their typical peers, and if this measure correlated with PSE – with the prediction being that children with higher speech rate will have a correspondingly higher PSE.

Word reading involves phonological encoding, translating the visual grapheme into its phonological form. It has been shown that DLD has an impact on reading; there is a high co-occurrence of reading disorders such as dyslexia with DLD and both conditions are linked with poor working memory (Bishop & Snowling, 2004; Carretti et al., 2009; Gathercole et al., 2006; McArthur et al., 2000; Nation et al., 2004). Phonological awareness is key to reading, and this involves holding words in mind and processing this information. As a result, it seems likely that there would be a correlation between reading ability and PSE, as both rely on children producing a phonological representation from a visual stimulus, either from a word or from a picture. In the current study, children were asked to complete both a sight word reading task and phonemic decoding (e.g., nonsense words) and the scores from each were totalled and used as the overall score.

The final 'additional' measure was expressive vocabulary. Although children with DLD present with very heterogenous profiles reduced expressive vocabulary is often a trait used to contribute to diagnosis (Sansavini et al., 2021). As a result, a significant difference was expected between the groups on a measure of expressive vocabulary, and in addition it was hypothesised that lower expressive vocabulary would correlate with a smaller PSE. Previous work has identified lower levels of cumulative rehearsal correlated with a lower score on a vocabulary assessment (Henry et al., 2000). A larger expressive vocabulary could have a knock-on effect to improved phonological encoding as children have a wider 'choice' of representations to access and these tend to be stronger representations that are as a result easier to call upon. However, increased expressive vocabulary also means that there is more likelihood of phonological confusion between similar items (simply due to more being present overall). Limited working memory may hinder vocabulary development, and it is also thought to be one of the key markers to DLD (Adlof & Patten, 2017). Here we would expect to see a correlation between PSE and expressive vocabulary.

Identifying relationships between factors such as these outlined and phonological encoding could support the development of clinical interventions to help children with DLD improve these skills and provide insight if there is a key underlying breakdown in phonological encoding. For example, if reduced processing speed correlates with a smaller PSE, it suggests a general cognitive difficulty impacts the process of encoding and retrieval, and intervention identifying ways to support efficient processing may be recommended. If a relationship is found between phonological encoding and expressive vocabulary, it may be that working on developing stronger vocabulary representations and increased breadth of vocabulary through targeted learning may in turn support phonological encoding and working memory (and, maybe, in turn, then develop further vocabulary development).

These considerations resulted in RQ3: Are there similar relationships in the DLD and TD groups between PSE and the following variables: reaction time, RAN, speech rate, reading and expressive vocabulary?

8.2 Method

Full details of methods of administration of these tasks are given in section 5.5.3. The five tasks which are the focus for this chapter were completed in the second session, after the self-report strategy section. The tests were administered either face to face or using the visualiser over Zoom for the online participants.

Speech rate was obtained by recording the child repeating the name of a picture presented on the laptop screen for thirty seconds. The length of time (in seconds) taken for ten repetitions was calculated from this information.

Reaction time was calculated using the 'Gorilla' software; participants had to press the space bar as soon as a picture was presented on the screen (position and length of time between presentations was varied). The participants were shown 18 pictures, once each. The length of time between presentation and key press was measured by the software and these scores (in seconds) used for the analysis.

The sub-tests from the CELF-4 (Semel et al., 1995) of Rapid Automatic Naming and Expressive Vocabulary were used for these measures. The phonemic decoding and sight word tests from the TOWRE (Torgesen et al., 1999) were used as the measures of reading – in this case the combined raw scores (number of words of each type read in 45 seconds) were used as the score.

8.3 Results

Results of each task are shown in Table 8.1. There were large standard deviations for most scores. A surprising observation was the DLD group outperforming the TD group on the reading measure, but this difference was shown to be non-significant (please see later).

Table 8.1 Means and standard deviations for related cognitive processes for each group

	Speech Rate Mean (SD)	**EV Mean (SD)**	**RAN Mean (SD)**	**Reaction Time Mean (SD)**	**Reading Mean (SD)**
All DLD (*n* = 72)	4.79 (1.43)	4.67 (2.56)	103.51 (30.48)	775.55 (340.09)	121.94 (43.24)
All TD (*n* = 58)	4.14 (0.99)	13.41 (3.47)	98.34 (28.26)	665.59 (266.23)	116.51 (37.75)
All 6-7 years (*n* = 67)	4.62 (1.27)	8.22 (5.42)	95.52 (20.44)	758.23 (280.83)	115.09 (39.99)
All 9-10 years (*n* = 63)	4.35 (1.31)	9.00 (5.11)	110.10 (34.92)	693.75 (343.00)	123.81 (41.55)
6-7 years DLD (*n* = 39)	4.93 (1.67)	4.31 (2.42)	94.44 (22.59)	818.51 (279.19)	114.51 (37.90)
6-7 years TD (*n* = 28)	4.20 (1.13)	13.68 (3.28)	89.86 (17.03)	674.27 (265.55)	115.89 (43.43)
9-10 years DLD (*n* = 33)	4.60 (1.58)	5.21 (2.63)	114.55 (35.43)	717.93 (400.52)	130.73 (47.90)
9-10 years TD (*n* = 30)	4.07 (0.89)	13.17 (3.74)	105.20 (34.27)	667.16 (270.41)	120.13 (32.31)

A Mann-Whitney *U* test was carried out between the DLD and TD group for each measure to identify any significant between group differences (this non-parametric test was used due to the large standard deviation and non-normal distribution of the data). These revealed significant group differences in Reaction time, with the TD group significantly faster than DLD ($U(N_{DLD}$ =

72, N_{TD} = 58) = 1672, z = -2.20, p = .028); Expressive Vocabulary, with TD scoring three-fold higher than DLD ($U(N_{DLD}$ = 72, N_{TD} = 58) = 84.5, z = -9.50, p < .001) and Speech Rate, with TD speaking faster than those with DLD ($U(N_{DLD}$ = 72, N_{TD} = 58) = 1419, z = -3.36, p < . 001). There were no significant differences between groups for reading or RAN. Correlational analysis was run between each related cognitive process for each of the groups (results in Table 8.2) which showed only relationships between RAN and Age in each group (DLD group R = *0.33, p* = .005; TD group R = 0.27, p = .037).

Table 8.2 Correlations between each related cognitive process (Speech Rate, EV, RAN, Reaction Time, Reading and Age) for each of the DLD/TD groups

DLD / TD	Speech Rate	EV	RAN	Reaction Time	Reading	Age
Speech Rate		R = -.14, P = .228	R = -.007, P = .952	R = .11, P = .379	R = -.06, P = .635	R = -.11, P = .341
EV	*r* = .25, *p* = .064		R = .15, P = .202	R = .10, P = .425	R = .13, P = .294	R = .18, P = .133
RAN	R = .03, *p* = .815	*r* = .05, *p* = .735		R = .12, P = .321	R = .13, P = .289	**R = .33, *p* = .005**
Reaction Time	*r* = .09, *p* = .492	*r* = -.21, *p* = .116	R = .22, *p* = .094		R = .02, P = .896	R = -.15, P = .215
Reading	*r* = .24, *p* = .066	R = .002, *p* = .987	R = .10, *p* = .455	R = .25, *p* = .063		R = .19, P = .113
Age	R = -.06, *p* = .642	R = -.07, *p* = .583	**R = .27, *p* = .037**	R = -.13, P = .920	R = .004, *p* = .976	

Given the presence of these significant group differences, analyses were run on the TD and DLD groups separately. The scores from all five tests were put into a multiple regression analysis in order to identify if any were significant predictors of PSE. Multiple regression analyses allow the consideration of whether a variety of independent factors contribute to a dependent factor and given the speculative nature of this question, this seemed an interesting and appropriate analysis to consider any interactions between these processes and PSE.

Robust checks revealed that despite the large standard deviations, there were no particular outliers and the data appeared robust. In addition, key statistical checks (multicollinearity, Durbin-Watson, tolerance and VIF statistics, Cook's and Mahalanobis distances, plots of standardised residuals and predicted standardised values, standardised residuals, partial plots) were within acceptable limits (Field, 2013). This reassured that the distribution of the data would not affect the findings from the parametric multiple regression analyses carried out.

8.4 Statistical Analysis

Linear regression models were used to determine the amount of unique and shared variance contributed to PSE by each individual factor (speech rate; reaction time; reading score; RAN and expressive vocabulary) after controlling for chronological age. Chronological age was entered in the first step of the model. Step 2 involved entering all of the above factors. This was initially done for each of the participant groups (TD or DLD) separately.

Proportional difference scores of PSE were used as the dependent variable. As discussed in section 6.4.3, the proportional difference score was calculated from the difference between the total trials correct for phonologically similar and dissimilar pictures (the absolute difference score), divided by the total trials correct for phonologically dissimilar pictures. This was chosen as the measure of PSE for these regressions because of the wide range of scores between TD and DLD groups, and the low overall total scores of DLD. The proportional score should remove the effect of differences in memory span and provide an indication of the degree of disruption to memory processes attributable to PSE. Summary details of step 2 of these regression analyses are shown in Table 8.3.

Results of multiple linear regression indicated that there was no significant relationship between the five independent variables detailed above (Reaction Time, RAN, EV, Speech Rate and Reading) and proportional PSE, in either group. For both groups, the overall regression models were not significant (TD: $F(6, 51) = 1.04$, $p = .413$, $R^2 = .004$; DLD: $F(5, 65) = 0.52$, $p = .642$, $R^2 = -.025$).

In looking at the standardised beta-values, there were no individual variables which were significant predictors for either group.

Table 8.3 Summary details of step 2 of regression analysis of the multiple regression analyses predicting PSE

			Details of Step 2 for each regression						
Group	**Final Model *F*(df)** **Adj. R^2**		**Age**	**Reaction Time**	**RAN**	**EV**	**Speech Rate**	**Reading**	**Change in R^2 Step 2**
TD	1.04 (6, 51)	**β**	.02	-.14	0.05	.28	-.08	.08	.108
	.004	**Unst. β**	.002	0.00	0.00	.02	-0.02	.00	
		SE	(.018)	(.000)	(.001)	(.009)	(0.031)	(0.001)	
	$p = .413$		$p = .907$	$p = .352$	$p = .714$	$p = .053$	$p = .589$	$p = .572$	
DLD	0.523 (5, 65)	**β**	-.007	-0.12	-0.10	.16	.12	-0.10	0.061
	-0.025	**Unst. β**	-.002	0.000	-.001	0.025	0.032	-.001	
	$p = .642$	**SE**	(.034)	(0.000)	(.002)	(0.019)	(0.033)	(.001)	
			$p = .960$	$p = .338$	$p = .450$	$p = .200$	$p = .344$	$p = .410$	

Harrell (2017) suggests that best practice for multiple linear regression is that there should be a minimum of 10 observation points/participants per predictive variable. In both groups, particularly TD (*N* = 58) the sample size is low for the number of variables. In light of this, the analysis was re-run on the whole group sample, but with an added third step of group (TD or DLD) entered as a dummy variable. The results are shown in Table 8.4. The findings were similar to the individual regressions – the overall model was not significant, indicating that none of the five variables contributed to explaining variance in the PSE ($F(7,122) = 1.56$, Adj. $R^2 = .029$, $p = .155$).

The lack of significance from the dummy variable in the model despite the univariate differences found in the earlier analyses, as well as the lack of significant difference for age difference, was a surprising outcome of these regression analyses. It is possible that these analyses failed to find significant relationships due to task administration or reliability issues. However, given the consistency of the findings (e.g., between TD, DLD and the groups combined), it seems more likely that the lack of significance is due to an absence of relationships between these variables and the PSE, but perhaps very small variance 'dilutes' the group difference that should be shown by the dummy variable.

Table 8.4 Summary details of step 3 of regression analyses predicting PSE with both groups' data combined

	Details of Step 3 for regression							
	Age	**Reaction Time**	**RAN**	**EV**	**Speech Rate**	**Reading**	**Group**	**Change in R^2 Step 2**
β	-.001	-.11	-0.05	.28	.08	-.06	.06	
Unst. SE	.000 (.019)	0.00 (.000)	-0.001 (.001)	.017 (.01)	.02 (0.02)	.000 (0.001)	.04 (0.10)	.001
p	.993	.237	.576	.075	.398	.502	.723	

8.5 Discussion

Analyses were conducted to address RQ3 - Are there similar relationships in the DLD and TD groups between PSE and the following variables: reaction time, RAN, speech rate, reading and expressive vocabulary? The results showed that in neither group were there any significant overall relationship between the five variables and the PSE. Therefore, these variables did not predict the PSE; nor are they likely to explain the difference in PSE between groups, at least in the formats investigated here. Therefore, the hypotheses made that each of these factors would relate to the PSE can be rejected.

Despite significant differences in performance between the groups in relation to three of the five variables as would be expected (reaction time, speech rate and expressive vocabulary), and significant differences in PSE between the groups, no significant relations were found between any of the measures and PSE. This suggests that the five variables involve different cognitive processes than those involved in PSE. Nevertheless, further research is needed before this conclusion can be accepted, given that there are arguments for shared cognitive processes between the five variables and PSE. This is especially important as there does not appear to have been previous research on this specific topic, even concerning typically developing children.

Furthermore, the replication of results across the two individual groups in the first model and the combined results in second model also suggest that this finding is robust. However, it also needs to be acknowledged that one cannot conclude that no relationships exist between variables on the basis of non-significant findings; larger sample sizes or different measures might in future identify significant relations. However, the findings in this chapter are valuable in providing initial information about the nature of these relations.

In terms of moving forward, this opens the door to considering other possibilities as to where the overlap lies, and a more in-depth consideration of the nature of the PSE effect in general, and of the specific underlying reasons for a reduced PSE in children with DLD.

To summarise, a variety of tasks known to be associated with working memory were administered in order to consider whether there are similar relationships in the DLD and TD groups between PSE and these variables (verbal strategies, speech rate, RAN, reaction time and reading).   This appears to be the first investigation of this issue. While significant differences were found between the two groups in Reaction Time, Speech Rate and Expressive vocabulary, there was a general absence of significant relations between thee five variables and PSE in either group or in the whole sample.

CHAPTER 9

General Discussion

This final chapter outlines the findings and conclusions from the investigations carried out for this thesis. The sections of this chapter concern: the background and motivation for this study, and identification of gaps in the relevant research literature; summaries of the findings about each research question together with potential clinical implications; consideration of strengths and limitations of the study; direction for future research and finally an overall summary and conclusions.

9.1 Background and Motivation for Study

This study was designed to add to the knowledge base concerning the development of phonological encoding in children with DLD between the ages of 6-10 years, through analysis of the phonological similarity effect. Phonological encoding is the process of producing a verbal label for a visually presented stimulus and is considered a key aspect of the working memory system, as it allows information to be retained in the phonological loop whilst processing occurs.

Phonological encoding can be investigated by using memory for visual items, e.g., pictures, which have readily accessible names that are manipulated for phonological similarity. By comparing the level of recall for phonologically similar pictures to phonologically dissimilar pictures, even when the material to recall is visual and recall is non-verbal, it is possible to identify whether phonological encoding is occurring. Furthermore, differences in recall of these two picture types are highly likely to be due to participants activating an internal phonological representation within the hypothesised phonological loop. Such activation is believed to take place via the use of processes akin to internal speech; these processes are also likely to draw on similar mechanisms to overt speech (Baddeley, 2010).

Previous work has found that phonological encoding appears to be consistently used by ages 6-7 years, around the same time that verbal rehearsal strategies start to emerge (Hasselhorn & Grube, 2003; Henry et al., 2012; Mueller et al., 2003; Palmer, 2000b). Verbal rehearsal strategies include various processes used to repeat 'to be remembered' information either internally or out loud, in order to keep it current and prevent decay in the phonological loop. Different types of verbal rehearsal strategies have been identified, including simple naming or the more complex 'cumulative' rehearsal, which appears developmentally later (Flavell et al., 1966; Hitch, Halliday et al., 1989; Jarrold & Hall, 2013; Kirchner & Klatzky, 1985; Lehmann & Hasselhorn, 2007; Miller et al., 2015; Poloczek et al., 2019).

There have been decades of research into general working memory processes and Developmental Language Disorder, as well as the interaction between the two. However, there is very limited research into: the specific process of phonological encoding and its development in those with Developmental Language Disorder; how phonological encoding might interact with verbal rehearsal strategies and development; and the relationships of phonological encoding to those processes known to be highly correlated with working memory and phonological encoding such as rapid automatic naming; reading; expressive vocabulary, speech rate and reaction speed. As such, the current thesis set out to begin to fill some of these 'gaps' in the evidence base.

The first area of interest concerned phonological encoding in children with DLD. Initial literature searches revealed that previous work into 'inner speech' processes in children with DLD tended to have focussed on a general area of self-directed speech: speech used to aid attention and problem solving, but for oneself rather than for social purposes (Abdul Aziz et al., 2017; Botting et al., 2013; Lidstone et al., 2010; Lidstone et al., 2011; Winsler & Naglieri, 2003). This was observed to occur out loud, under one's breath or was reported to be internal (the ‘inner voice’ or monologue that helps us stay on task). While there appears to be overlap in these topics, (for example age of development and pattern of development is similar in phonological encoding and self-directed speech) and often this self-directed speech was investigated through working memory tasks, little was found in the evidence base specifically about phonological encoding in children with DLD, relating to working memory.

The second area of focus within the current thesis was that of verbal naming and rehearsal as working memory strategies. This also overlaps with, but is not synonymous with, self-directed speech. However, work has mainly focussed on typically developing children and not those with DLD. In the typically developing population, evidence for use of these strategies has been found consistently in children as young as 4 years (Poloczek et al., 2019), although these processes may not enhance performance until they become more refined – so although a child may report the use of rehearsal, or be observed to repeat the name of a stimulus before being asked to recall it, this does not always correlate with improved performance in the recall task.

In the case of free recall tasks (where larger sets of items are attempted to be recalled and order is not important) as opposed to immediate serial (ordered) recall, previous work has also identified the rehearsal strategies used by young children (Lehmann & Hasselhorn, 2007). It is apparent that different versions of these strategies may overlap with each other, as over time children begin to deploy them more strategically, in line with Siegler’s theory of development: ‘overlapping waves’ (Siegler, 1999). There is a pattern of development for the verbal strategies, from simple naming to cumulative rehearsal (adding each item to the previous and repeating them), but there is not necessarily step wise progression. Instead, there seems to be a gradual development where multiple strategies may be used even within one task.

The final area of interest for the current thesis was more speculative. There are many other processes that are known to correlate with working memory, and one could hypothesise that some of these would utilise similar 'skills' to that of phonological encoding. Investigating the overlap between these other associated skills and phonological encoding could potentially help to identify areas that contribute to the process or further shed light on potential areas of breakdown in children who have difficulty with both tasks. The associated skills considered were: processing time (through reaction speed, articulation rate and Rapid Automatic Naming); reading; and expressive vocabulary.

Processing time is often cited as a driver for working memory capacity, due to the need to hold an item in mind whilst carrying out a cognitive task. Increased processing speed is associated with increased memory capacity (Bayliss et al., 2005). If processing speed is faster, it follows that one is better placed to rehearse and complete the task easier to allow more efficient recall, and so a faster reaction time may correlate with an increased PSE and increased use of verbal rehearsal. Similarly, Rapid Automatic Naming (RAN) measures how quickly a word can be retrieved from a visual image and the relevant word spoken. Phonological encoding requires a verbal label to be retrieved from the phonological store and then held in mind internally, so one could presume that a faster RAN correlates with increased phonological encoding, evidenced through a larger PSE. As rehearsal occurs in real time internally, increased speech rate should increase the opportunity for more rehearsal, improving working memory. As processing speed is believed to be slower in children with DLD (Montgomery et al., 2010), it was thought that there might be correlations between processing speed and PSE.

Like children with DLD, children with reading difficulties, such as dyslexia, also commonly demonstrate weaknesses in phonological short-term memory (Gray et al., 2019). This is unsurprising when one considers the processes involved in reading also rely heavily on the use of the visuo-spatial sketchpad and phonological loop. The visual input (the written word) automatically enters the visuo-spatial sketchpad (Baddeley, 1986) but it can also require phonological encoding, to translate the written (visual) word into a verbal label. There are also additional levels in reading, for example phonological awareness to identify the sounds produced to 'sound out' new or non-words, compared to visual recognition for sight words. Previous work suggests that, in terms of strategy development a 'layered' effect is observed, with children using a visual strategy (suggesting no phonological encoding) at a younger age, before moving onto phonological encoding of the written word around 6-7 years (Palmer, 2000b). At least 50% of children with DLD are thought to also have a reading difficulty, with some estimates as high as 84% (Botting et al., 2006). The current study considered whether these inter-relations would result in differences in reading ability between the DLD and TD groups, and whether there were relations between PSE and reading.

The final 'associated skill' considered was that of Expressive Vocabulary. The nature of DLD is that it involves reduced vocabulary, delayed vocabulary acquisition and difficulties in use of vocabulary (Hick et al., 2002; Petruccelli et al., 2012; Rice & Hoffman, 2015). Theories of word learning include the use of the phonological loop to hold items in mind while they are processed and stored as a representation in long-term memory (Baddeley et al., 1998), and that a breakdown here could reduce word learning. This then can be a self-fulfilling problem such that further vocabulary acquisition is impaired as less 'bootstrapping' can occur, whereby new words are mapped according to similar features of words already known. Consequently, there may be processes involved in vocabulary acquisition which involve (or are similar to) the PSE. For example, being able to accurately store a phonological representation without interference from other phonological representations held in short-term memory.

In summary, the present study was designed to address some of the identified gaps in the previous research literature by investigating the following research questions. (1) Do children with DLD have difficulties with phonological encoding compared to age and non-verbal IQ matched typically developing children? (2) Does the development of verbal naming and rehearsal strategies follow the same pattern in children with DLD between 6 and 10 years as their age and non-verbal IQ matched typically developing peers? (3) Are there similar relationships in the DLD and TD groups between phonological encoding and the following variables: expressive vocabulary, speech rate, RAN, reaction time and reading?

The next three sub-sections summarise the findings in response to these questions.
The remainder of this chapter considers these findings and their significance or potential impact within the wider context of DLD and clinical interventions.

9.2 Findings of Research Question 1 - Do children with DLD have difficulties with phonological encoding compared to age and non-verbal IQ matched typically developing children?

The results of chapter 6 revealed that children with DLD demonstrated a significantly smaller phonological similarity effect than their typically developing peers. This suggested that, although phonological encoding was occurring, it was not employed to the same extent by children with DLD. As stated above, a phonological similarity effect is reported when a list of phonologically similar items is recalled in serial order with less accuracy than a list of phonologically dissimilar items. The presence of a PSE suggests that phonological encoding – generating the verbal label of the image seen – is occurring, as otherwise the 'sound' of the word would not influence recall.

These results were in line with predictions, which were based on previous research looking at the development of PSE in typical children. In typical children, the PSE has been observed from the age of around age 6-7 years (Hasselhorn & Grube, 2003; Henry et al., 2012; Palmer, 2000b). As children with DLD have a smaller memory span, it was thought they would be likely to resemble younger chronological age peers, so it was predicted that this may mean they do not employ phonological encoding in verbal working memory tasks to the same extent as same age peers (particularly the younger group). A small PSE was found in children with DLD, even in the younger (6-7 years) age group, but the typically developing children demonstrated a significantly larger PSE, which did not interact with age, confirming a difference in use of phonological encoding between the two groups. What was unexpected was that there was no significant difference found between the two age groups (6-7 years and 9-10 years), in any of the measures.

These findings are consistent with the fact that some studies *have* found a PSE in children younger than 6 years (i.e., in children with a lower overall memory span) (Al-Namlah et al., 2006; Jarrold & Citroën, 2012; Tam, Jarrold, Baddeley, & Sabatos-DeVito, 2010), although these were small scale studies and used a different methodology (e.g. verbal presentation or verbal recall, so not testing 'pure' phonological encoding). The findings are also consistent with previous literature showing improvements in memory span with age (e.g., Henry et al., 2000) and weaker performance on short-term serial order memory tasks in groups of children with DLD (Henry &

Some argue that phonological encoding and the PSE are present at younger ages, and do not suddenly 'appear' at age 6 years. For example, Jarrold and colleagues suggest that there could have been a failure to detect small PSEs in the youngest children in the studies cited above, due to using the 'absolute PSE size' when measuring it (Jarrold et al., 2015; Tam et al., 2010). They argue that this is because the PSE is usually calculated from looking at differences in 'absolute' recall of similar and dissimilar items. If memory span for both types of items is low, differences in recall between these item types may not be identified because of a proportional scaling effect. Thus, presuming the PSE is 'absent' could be incorrect. Jarrold and colleagues, therefore, propose that the PSE is better assessed in a way that ensures it is proportional to baseline memory span. They argue that by using a proportional measure, the PSE can be identified at lower absolute span levels. Further, their findings suggest that using this measure, the presence and size of the PSE is consistent across age groups, in a way that is proportional to memory span level, even if baseline memory span is very low.

As children with DLD are known to have a low 'absolute' span due to reduced working memory overall, it could be argued that children with DLD may show a PSE when proportional differences scores are used, whereas this might not be observed using 'absolute' difference scores. To address these methodological issues, the PSE was investigated using absolute and proportional scores. The results detailed in section 6.4 showed clearly that the children in the DLD group had a smaller PSE both in absolute and proportional terms, compared with TD peers. There was no significant difference between the age groups in either the TD or DLD groups, thus, the findings about proportional scores used support the argument that the PSE could be related to span size and that there is not necessarily a difference in the size of the PSE for children between the ages of 6 and 10 years.

Jarrold et al.'s final caveat to the 'proportional effect' argument about the PSE is that there is a lower limit to memory span performance below which a PSE cannot be identified. At this 'floor' level, the impact of serial order is lost (the requirement to preserve serial order in memory becomes irrelevant due to only having to recall 1-2 items, unlike in a longer list where retaining the order is more effortful) and this affects the scaling of these scores. According to this argument, when 'scaling' proportionally, it is not possible to generate the PSE for those with extremely low memory span scores. However, in the current study, a PSE was identified even in the DLD group at lower span levels, and the significant difference between the size of the PSEs between the two clinical groups remained; further, it was also observed with measures reflecting the absolute size of the PSE, using both total trials correct and overall span measures. Thus, it is unlikely that the PSE went undetected in the present study.

Indeed, although the PSE is thought to occur due to potential confusion between items within the phonological store, although it can also occur at the recall stage if confusion arises as similar items are confused at output (Baddeley, 2007; Cowan, Saults, Winterowd, & Sherk, 1991; Hasselhorn & Grube, 2003). The reduction in 'confusion' and resulting smaller PSE in children with DLD could be due to their reduced use of phonological encoding as items are presented; or it could be due to reduced access to stored phonological representations at the recall phase. It is important to emphasise that the current method involved non-verbal (pointing) at recall, which means that confusion would only arise at the recall stage if the child chose to verbalise the names of items internally as they were selecting, searching, and pointing to them during the recall process. However, if this verbalisation did occur, it would be possible for more errors to arise for the phonologically similar lists, even with a list length of one, as the children were presented with a full matrix of all nine items to scan and identify the picture/s they had seen. Thus, this introduced another opportunity for phonological similarity confusion to arise.

Consideration of how to 'improve' phonological encoding and whether this would result in better overall language will be discussed below, with a consideration of the clinical relevance to children with DLD and potential impact on interventions.

9.2.1 Clinical implications of RQ1 findings

The limitations in phonological encoding observed in children with DLD have relevance to theories which argue that there is a cycle of impairment. It has been suggested that DLD involves a cycle of impairment whereby difficulties with phonological short-term memory makes it hard to learn new words and transfer these to long-term memory. Phonological encoding is part of the phonological short-term memory system, and phonological encoding enables the creation of phonological representations which usually provides the basis for a more effective way of memorising 'visual' items (that are nameable) than a method which uses the visual representations directly (Henry et al., 2012). Encoding visual items into phonological representations allows information to remain 'current' for longer in the phonological loop, because this loop has a greater capacity and a mechanism for verbal rehearsal, i.e., recycling the input for as long as needed. The finding from the current thesis that children with DLD do not appear to utilise phonological encoding of visual material to the same extent as their peers could be due to several causes. For example, it could be because they have poorer phonological short-term memory capacity, or because they lack the resources or capacity to carry out the phonological encoding. As a result, they could create 'weaker' phonological representations than typically developing peers who encode visual stimuli more routinely. Taking this further, when these phonological representations are transferred to long-term memory, they are likely to result in less detailed and accurate representations than in TD children. As a result, there could be a less rich, well-defined store of phonological representations in the long-term memory. This in turn may result in less effective use and access to phonological representations (e.g., when stored information is drawn on via the episodic buffer) when they are needed for phonological encoding and similar processes (Jones, S. & Westermann, 2021). In the research for this thesis, the words selected were high frequency and it was checked that children were familiar with them; even so, the children with DLD may still have had less detailed and 'fuzzier' phonological representations of these words than the TD children (McGregor et al., 2017).

It is also possible that the difficulties observed in children with DLD with phonological encoding may in part be due to the access and retrieval of phonological representations rather than the creation of these representations (Mengisidou & Marshall, 2019). Children with DLD often have word-finding difficulties, and one hypothesis is that these could be caused by failures to access phonological representations (Messer & Dockrell, 2006). Consequently, it is possible that the problems with word-finding and phonological encoding are related processes. If this is the case, interventions may aim to create stronger links between long-term stored knowledge and the phonological loop system. If retrieval / access to stored representations became more automatic for phonological encoding, this might result in improvements of other forms of phonological retrieval.

It is a challenge to know how to formulate interventions which could address this issue. One simple idea could be to find ways to encourage children with DLD to utilise more phonological encoding in everyday life – for example, to name out loud images or to talk aloud about things that they see, and then gradually withdraw this requirement so it becomes a more automatic response. This should increase the amount of phonological encoding and also potentially develop stronger long-term phonological representations and increased the efficiency of retrieval of these representations through practise.

Another approach might be to compensate for the difficulties in phonological encoding and focus on increasing children's exposure to targets, perhaps through minimal pairs work to help expose phonological differences. This could involve showing visual and verbal stimuli of words that sound very similar except for one phoneme, to encourage children to listen carefully to discern the difference between them, and therefore strengthen their own phonological representations. A final possibility is to use Hebb Repetition Learning method, which focuses on using repetition to consolidate implicit forms of learning, for example for serially ordered items such as novel word forms or lists of items (Henry et al., 2022). Such a technique might form the basis for an intervention because the simple repetition of visual and phonological representations might be expected to increase the links between the two forms of representations as would the naming of visual items (as described above). However, it needs to be borne in mind that Hebb learning might be impaired in those with DLD (Hsu & Bishop, 2014).

Recent evidence has demonstrated that a working memory intervention focussed on the central executive for children with DLD increased several untrained working memory skills and language comprehension (Henry et al., 2022). Children with DLD who received the WM intervention showed significantly larger improvements on untrained WM abilities (including phonological short-term memory) and sentence comprehension, compared with an active control group. The fact that phonological short-term memory and language comprehension scores improved (without these skills being directly targeted) suggests that such an intervention could have an application to helping phonological storage and encoding. It seems that targeting working memory and phonological encoding could improve language outcomes in children with DLD, by increasing their ability to use the phonological loop in word learning (Jackson et al., 2019). Consequently, improved ability to recall and store representations appears to improve access to them and the more accurate storage permits better understanding of the words involved.

Other skills related to phonological encoding are likely to be important when identifying how to support children with DLD – and verbal rehearsal strategies are an important possibility. The findings regarding verbal rehearsal strategies will be described in the next section.

9.3 Findings of Research Question 2: Does the development of verbal naming and rehearsal strategies follow the same pattern in children with DLD between 6 and 10 years as their age and non-verbal IQ matched typically developing peers?

Chapter 7 focussed on the self-reports given by children about the strategies they used in the recall tasks. Children were asked to complete the initial memory span tasks again, at their span level and just above their span level. After each trial the children were asked to choose one of a selection of five strategies to indicate how they remembered the pictures (no strategy, visual rehearsal, simple naming, complete rehearsal, or cumulative rehearsal). Three of these were verbal in nature, i.e., required phonological encoding to carry them out: simple naming, complete rehearsal, and cumulative rehearsal. Corresponding to the first set of findings (that size of the PSE significantly differed between groups, with smaller levels of PSE in the DLD group) the use of verbal rehearsal strategies also differed significantly between the groups, with evidence for less developmentally mature strategy use (e.g., less cumulative rehearsal) in the DLD group.

In order to carry out verbal rehearsal strategies (i.e., naming, complete rehearsal or cumulative rehearsal) in this task, children would need to encode the stimuli by producing an internal phonological representation, due to the non-verbal presentation of the stimuli (they all appeared as visual images of common objects). As a difference in the size of the PSE between DLD and TD groups was observed in chapter 6 it is likely that the differences in verbal rehearsal strategies could have been responsible for this effect. Hence, the self-reported strategies were of considerable interest. In fact, the children with DLD, still reported using a range of strategies (verbal and non-verbal), and many did report cumulative rehearsal. However, the difference between the TD group and the DLD group appeared to lie in the frequency of selection of cumulative rehearsal. The TD group demonstrated significantly greater frequency of selection of cumulative rehearsal, whereas children with DLD used a wider spread of all the choices of strategies rather than focussing on one (i.e., cumulative rehearsal), and, therefore, showed a continued reliance of less mature visual rehearsal (or no strategy) rather than more efficient verbal rehearsal methods.

Siegler's overlapping waves theory suggests that children do not develop strategic competence linearly but introduce new strategies in waves (Siegler, 2000). This theory assumes that children typically use a variety of strategies, not just one, to solve a problem; that there are prolonged periods of overlap between these strategies rather than brief transitions. Siegler (2000) further suggests that change occurs in regard to which strategies are relied upon and how they are used, as well as through the introduction of new strategies. Over time some strategies cease to be used, and others take on greater prominence, with a movement towards the most efficient strategies, although these take time to be 'learned' and used effectively. Looking at one time point, it is possible to observe multiple strategies being used, as was found in the self-reported rehearsal strategies used in the current thesis (see section 7.3). Both the TD and DLD groups reported a range of rehearsal strategies being used across the trials, but the TD group reported a higher frequency of the more advanced cumulative rehearsal; the DLD group self-reported a more even spread of all the offered strategies. This suggests that children with DLD are at an earlier point in the development of their verbal rehearsal strategies and strategic maturity.

In the interpretation of these findings, it has been assumed that cumulative verbal rehearsal is developmentally more advanced than the other strategies and requires more cognitive resources to execute – the child needs to name the item (i.e., phonologically encode the visual image into a verbal label), then repeat the name, and then add this name to the previous items in the list, all of which must be repeated for the next item. There is good evidence to suggest that naming is developmentally less mature than cumulative rehearsal, with cumulative rehearsal being reported more in use by 10-year-olds than 7-year-olds (Henry et al., 2000); further, an increased accuracy in span overall is also associated with use of cumulative rehearsal compared to naming (Poloczek et al., 2019). However, it is possible that at first, the cumulative rehearsal strategy could be detrimental to recall as the effort of using it reduces the capacity for recall (McGilly & Siegler, 1989), as there is a greater opportunity for interference. There may be enough successful recalls with cumulative rehearsal such that the children continue to use it and as a result become more proficient and successful in recall (Palmer, 2000b). As a result of this practice, the more advanced strategy becomes more efficient and can become a preferred recall strategy, with cumulative rehearsal the most efficient for both accuracy and span by around age 10 in typically developing children (Palmer, 2000a). According to this explanation, it seems likely that the children in the DLD group were at an earlier 'stage' of using cumulative verbal rehearsal and refining its use.

If it is the case that children with DLD are at this earlier stage of development, this is a potential area to consider clinically – in terms of understanding the impact of the reduced use of 'advanced' rehearsal as well as a potential therapeutic target.

9.3.1 Clinical implications of findings in relation to RQ2

While some suggest that increased use of verbal rehearsal strategies does not correlate with or improve memory performance in children with DLD as it does for children with TD (Rice & Hoffman, 2015), there is other evidence of potential benefits from training in verbal rehearsal strategies in groups with neurodevelopmental conditions. For example, in one such study, a PSE was shown to develop (where it was previously absent) in a group of adults with Intellectual Disability who were trained in cumulative verbal rehearsal methods (Clerc & Courbois, 2017). This could mean that this training was effective at developing phonological encoding – although this method involved verbal rather than non-verbal recall and overt rehearsal was encouraged. Consequently, previous research findings and the findings from this thesis suggest that targeting rehearsal strategies could be of assistance to children with DLD. Interventions might involve practicing, scaffolding, and explaining rehearsal strategies to these children, with further work needed to identify whether such interventions are effective.

Another possible approach is training on working memory tasks to attempt to increase capacity. Recent evidence has demonstrated that a working memory training intervention focussed on the central executive for children with DLD increased performance on several untrained working memory skills as well as on language comprehension (Henry et al., 2022). Children with DLD who receive the WM intervention showed significantly larger improvements on untrained WM abilities (including phonological short-term memory) and sentence comprehension, compared with an active control group. The fact that phonological short-term memory and language comprehension scores improved (without these skills being directly targeted) suggests that such an intervention could have an application to helping phonological storage and encoding. It seems that targeting working memory and phonological encoding could improve language outcomes in children with DLD, by increasing their ability to use the phonological loop in word learning (Jackson et al., 2019).

Some previous investigations into more general 'inner speech' processes, such as self-directed speech, found that children with DLD appeared to use more overt self-directed speech than their TD peers, potentially due to less internalisation having occurred (Abdul Aziz et al., 2017). Vygotskyan theory suggests that initially these processes occur overtly, and over time children begin to carry them out in their head instead. An interesting informal observation by the researcher when carrying out this experiment was that the children with DLD required many more prompts to complete the memory tasks silently, to ensure only internal processes were utilised. Whereas the TD children never required more than one prompt, frequently the DLD children were reminded on each trial to complete the task 'in their head' instead. They sometimes denied saying the words out loud, but still proceeded to whisper them even after the prompt, apparently unconsciously. At times children with DLD were observed to be using cumulative rehearsal due to the overt nature of their spoken response, but when this was suppressed by reminding them to complete the task 'in their heads' they reported naming or visual strategies. What was observed informally was that the children with DLD appeared to have more difficulty suppressing their external, out loud rehearsal or naming without repeated prompts. Perhaps one area of difficulty for children with DLD is their ability to internalise verbal rehearsal strategies. Taking more formal notes and observations of these behaviours in response to prompts to keep the task 'in their head' could be an interesting area for further research and intervention.

The fact that children with DLD were observed to find internalising phonological encoding and verbal rehearsal strategies difficult could mean they are at an earlier stage of development whereby these processes still occur 'out-loud' (although it should not be discounted that they are likely to have received other interventions in similar 'settings' which encourage them to talk out-loud during similar tasks).

Thus, when external verbal rehearsal strategies were not permitted or discouraged, this could have meant that, for children with DLD, there was less evidence of phonological encoding (the PSE was smaller) and reduced evidence for advanced verbal rehearsal strategies (less reporting of cumulative rehearsal). In practical terms, this could result in poorer performance in classroom tasks where silent working is enforced, or individuals feel inhibited to use private speech when observed. This could also be linked to executive function, requiring the shifting and splitting of attentional resources – and the effort of inhibition. If this is the case, supporting the development of overt verbal rehearsal strategies could reduce processing demands and corresponding improvements in performance may be observed. Potential intervention could involve devising classroom-based tasks that permit or encourage overt rehearsal and private speech, or developing the ability to do this 'overtly' but quietly or silently – e.g., whispering under one's breath or simply mouthing the words. Internal versus external speech during tasks could be an interesting starting point for future research, and should be considered in terms of classroom strategies and interventions when treating children with DLD or indeed those with working memory difficulties.

The findings that there were significant differences in both the degree to which a PSE was shown and in terms of the use of verbal rehearsal strategies between children with and without DLD leads on to the final part of the thesis. This next section explores whether these differences were related to other, theoretically overlapping skills, and whether understanding of such relationships could assist in identifying potential interventions to support development in this clinical group.

9.4 Findings of Research Question 3: Are there similar relationships in the DLD and TD groups between phonological encoding and the following variables: reaction time, RAN, speech rate, reading and expressive vocabulary?

In chapter 8 a multiple regression approach was taken to see whether some key variables, thought to relate to phonological encoding, were related to the degree of the PSE in the two groups of children. Using the independent predictor variables of reading, RAN, speech rate, reaction time, and expressive vocabulary, as well as age, it was assessed whether these variables contributed to predicting the PSE scores. The proportional difference score was used as the measure of the PSE, as this measure reflected the score that best captured the extent to which each child showed evidence for proportional differences in memory span between similar and dissimilar items. At first, the models were run separately for each group to compare findings between children with DLD and TD; subsequently the groups were combined to increase the power of detecting contributions of the five variables to the prediction of degree of PSE.

There was no significant contribution found for any of the five predictor variables to the PSE in either group, except a narrowly significant contribution of expressive vocabulary to the PSE in the TD group. When the data from the two groups were combined, no significant relationships or contributions emerged from these factors to the PSE measure.

While it was disappointing to see no relationships between these variables and the PSE in either group, the findings were not entirely surprising. The theory that there would be contributions from these variables to the PSE was based on previous research that has identified overlap between the individual processes each of these five variables and phonological short-term memory, with the logic that these variables would potentially use the same pathways as phonological encoding (and therefore contribute to the PSE). The one significant finding, that expressive vocabulary contributed to the PSE in the TD group, must be interpreted with caution, as the overall regression model was not significant. However, future research could explore this possible relationship in more detail, as more (and better quality) representations of phonological and semantic information about words within long-term memory could boost phonological short-term memory if phonological encoding takes place. In Baddeley's (2000) revised working memory system, the episodic buffer is the conduit through which all stored language knowledge in long-term memory is used to support other working memory systems, including phonological short-term memory. Therefore, a child who has a greater volume and clarity of long-term memory representations for individual words (and each word has more 'neighbours') might show greater confusion between similar sounding items at the recall level (Jackson et al., 2019) if they use phonological encoding and verbal rehearsal strategies.

However, the absence of relationships between the five associated processes and the PSE reported in this thesis is in line with the mixed findings in prior research. For example, although it would make sense that processing time impacts phonological encoding, there is also evidence that speech rate does not impact short-term memory capacity (Hulme et al., 1984).

Overall, the findings from RQ3 suggest that further work is required to better understand the underlying processes involved in phonological encoding and how these might manifest in other related working memory activities, and their clinical potential.

9.4.1 Clinical implications of RQ3

While the findings of chapter 8 did not identify specific differences between the groups or identify (robustly) any associated skills that that contribute to the PSE, they underline the lack of understanding of this area, and the importance of considering working memory holistically when targeting phonological encoding and the PSE in relation to its possible impact on language development. For example, it is known that reducing central executive load, providing memory support to reduce the processing required, or focussing on introducing new skills via familiar concepts rather than too much new 'content' simultaneously can result in better outcomes in working memory interventions (Alloway & Alloway, 2009). In order to focus on helping children with DLD to use internalised speech strategies such as phonological encoding and verbal rehearsal strategies, further research will be needed to explore this area in more depth.

9.5 Summary of all findings

The findings from this study overall demonstrated a significant difference in the extent of phonological encoding between children with and without DLD, across the age range of 6 – 10 years, as well as a significant difference in the use of verbal rehearsal strategies between these two groups. In both cases, as predicted, children with DLD had lower levels of PSE (presumably due to reduced phonological encoding) and demonstrated less complex verbal rehearsal strategies than their typically developing peers.

Consequently, the answers to the original research questions are as follows:

> RQ1) Children with DLD *do* have difficulties with phonological encoding compared to age and non-verbal IQ matched typically developing children.

RQ2) The development of verbal naming and rehearsal strategies *does not* follow the same pattern in children with DLD between 6 and 10 years as their age and non-verbal IQ matched typically developing peers.

RQ3) *Neither* the DLD *nor* TD group demonstrated relationships between phonological encoding and the following variables: reaction time, RAN, speech rate, reading and expressive vocabulary.

These findings are of interest because they suggest a difference in phonological encoding and the reported use of verbal rehearsal strategies between children with and without DLD. This is consistent with previous work looking at difficulties in various working memory components for children with DLD (Henry & Botting, 2017), difficulties which often persist throughout development despite language developing during this time (Graf Estes et al., 2007). The children with DLD in the present study demonstrated group differences at both age levels, even though vocabulary (and therefore long-term phonological representations) were presumably increased in the older groups. It is possible that children with DLD have a general developmental delay in that their phonological encoding and verbal rehearsal abilities develop at a slower but similar rate to that seen in TD children.

While phonological encoding is a necessary precondition for verbal rehearsal strategies to be used (in a non-verbal short-term memory task employing nameable items, such as in the current thesis) it does not automatically follow that verbal rehearsal will then occur (Jarrold et al., 2015). A child may use phonological encoding but then not choose to repeat either singly or in sequence the list of items names. Furthermore, it is not necessarily the case that verbal rehearsal is what drives developmental change in terms of short-term or working memory development (Jarrold & Citroën, 2012). While previous research has shown that the use of cumulative rehearsal increases developmentally, there was no significant difference found in its use between age groups in this study, and further work is required to confirm the developmental pattern in those with DLD. It is still possible that children with DLD may continue to rely on 'simpler' rehearsal strategies even at later stages of development, as there was no difference observed in the strategy choices they reported between the ages 6 and 10 years in the current sample.

Considering the results overall, one effect of the reduced phonological encoding and lower proportions of reported verbal rehearsal observed in children with DLD could be on vocabulary acquisition. Many researchers have proposed that phonological encoding, and in particular verbal rehearsal, may be essential for word learning (Baddeley et al., 1998; Gathercole et al., 1999; Snowling et al., 1991). Having impaired phonological short-term memory means there is a weakness in holding in mind information in the phonological loop, which impacts the ability to create long term representations for new words and therefore impacts vocabulary development (Gathercole & Baddeley, 1990). Children with DLD were less likely to use phonological encoding to 'most efficiently' recall sequences of items that were nameable (although presented as pictures). This could indicate a delay in automatically converting nameable material from a visual to a phonological code, reducing opportunities to consolidate vocabulary learning. This reduction in opportunities to consolidate vocabulary learning could then produce a cycle that further reduces new vocabulary growth, as the larger the vocabulary the easier it is to create new representations. As vocabulary increases, new words can be 'boot-strapped' more easily as more representations exist already to be mapped onto (Gray & Brinkley, 2011). Reductions in the use of phonological encoding and verbal rehearsal strategies mean that processes related to phonological storage of word forms are not practiced and automatised as much as they could be. This could also impact on phonological short-term memory capacity due to lack of opportunities to practice efficient phonological recoding and subsequent verbal rehearsal, to best use the available resources, and in children in DLD this deficit impacts on word learning (Alt & Spaulding, 2011).

Much work has been carried out looking at phonological short-term memory in children with DLD, with some citing this as a potential underpinning cause of DLD, or at the very least a consistent and useful diagnostic marker of the condition (Conti-Ramsden et al., 2001). Children with DLD are a heterogeneous group, presenting with very different profiles, however, the most consistent features across different children with DLD are phonological short-term memory impairments and reduced vocabulary – receptive, expressive or both (Conti-Ramsden, 2008). It is also known that phonological short-term memory predicts vocabulary knowledge in children with and without DLD (Baddeley et al., 1998), and that phonological short-term memory might constrain vocabulary acquisition (Gathercole, 1998).

All this suggests that research on these topics could be key to identifying ways to support children with DLD. Research reported in this thesis is relevant to these issues. For example, the difficulty faced by children with DLD seems to be that phonological encoding may not be as developed as their peers at the same age. In other words, it may be that the thought processes of children with DLD are less based around words and language than those of their peers, and this influences their overall development. Additionally, in non-verbal tasks and in everyday experiences, phonological encoding can be beneficial for remembering and is required as a first step before verbal rehearsal, so children who do not use these strategies will face rapid decay of the short-lived representations (Baddeley, 2000). Verbal rehearsal strategies support the development of phonological short-term memory and other related processes, so training in phonological encoding and verbal rehearsal could aid children with DLD to use these strategies more flexibly when verbal forms of remembering are more efficient than visual (Alt & Spaulding, 2011). In this way, understanding in detail what drives performance on short-term memory tasks for nameable visual items could lead to identifying ways of supporting language and vocabulary development in children with DLD.

In terms of understanding DLD, these results lend weight to the idea that DLD involves a limitation in phonological short-term memory capacity. This results in a reduction in phonological encoding and/or the use of verbal rehearsal strategies during everyday functioning, and this might be expected to affect the children's ability to use internal speech. It might also be expected to affect word learning, although the lack of correlation with expressive vocabulary reported in chapter 8 does not support this. The findings are consistent with models which suggest language and memory systems intricately interact with each other. While identifying a 'cause' of DLD is well beyond the reach of the present research, it is possible to speculate about the pathways of causality between the systems. Being less able to store accurate phonological representations is likely to mean that they are less well accessed and more challenging to rehearse, which makes them harder to recall and leads to less accurate representations being stored, and so a potentially adverse cycle is created. The point of 'break down' in this process is not clear, but the outcome is apparent. The DLD group were overall less 'vulnerable' to PSE, which suggests their language system was also less sophisticated in this area of functioning. It may be that these children have a less developed phonological network of interconnections between similar phonological representations, which means items are kept more distinct and are less likely to have interference from related items similarly to a pattern seen in semantic representations (Nilson et al., 2021).

9.6 Strengths and Limitations

This penultimate section will consider first limitations and then strengths of the methodology of the study.

In terms of imitations, the most conspicuous factor impacting the process of this study was the COVID-19 pandemic. Lockdown was enforced 18 months after the start of the three-year project, at the peak of data collection, and as a result the protocol had to be completely rewritten to change from face-to-face testing to online. Although every effort was made to make 'post-Covid' data collection as consistent as possible with face-to-face data collection, meeting children online rather than in person did change the process. The main task had been laptop-based from the start of the investigation, yet for on-line data collection there was a change in the dynamic from the researcher supporting the child to relying on parents/carers to offer this support. While expectations were made clear in terms of letting children complete the tasks independently, inevitably there were some occasions where parents/ carers needed prompting from the researcher – e.g., not to lead the child, and to suppress any verbal output to ensure the task was silent. The online set up also reduced the amount of informal observation that could be made, especially in the memory tasks where strategies were self-reported; here, physical manifestations of rehearsal could often be seen in person that were invisible online, e.g., children tapping their fingers or feet as they repeated words in their heads. However, tests were run to check there were no statistical differences between the data collected online and that from face-to-face encounters (none were found), so although the breadth of qualitative data was reduced there can be confidence in the overall findings from the study.

Secondly, the tasks required good (verbal) comprehension of what is being asked, at a level that is high especially for younger participants with severe DLD. Precautions were taken to pre-empt this by explaining tasks clearly and including practice items. For example, there was a comprehensive introduction to strategy use and how to self-report strategies, with practice trials with feedback before commencing. Visual examples of each strategy were explained verbally by the researcher to each child. However, it is prudent to note that some children may not have fully followed the task brief. Children with DLD required more frequent prompts to complete the tasks silently, and at times this means the articulatory rehearsal mechanism could have been 'externally' activated, resulting in potentially confounding the findings that this task measured a purely internal process of phonological encoding.

There were some unavoidable potential confounding factors in the main task – as well as the challenge of avoiding children from saying the stimuli out loud, at the other end of the scale it is impossible to confirm that children who completed the task accurately and internally were using the 'correct' word – for example, 'boot' instead of 'shoe'. This is an issue in the phonologically similar words if for example 'can' was encoded as 'tin'; 'van' as 'truck' etc. This was limited as much as possible through naming the words for each child initially to model the correct labels; screening at a recruitment level in order to only exclude children who may have a dominant language which could result in them using non-rhyming alternative labels in their heads.

The strategy task was titrated to each individual's span level (taken from performance in the initial task) and prompts for strategy choices were asked after each trial, in order to avoid any decay between actual recall and gathering information about varying strategies used. However, some participants were noted to use the 'no strategy' response if they had not been paying attention to the picture stimuli, or had forgotten them, or were unsure how to respond. There was also no option for any 'alternative' strategy other than those provided, and participants were directed to choose the closest if they felt it didn't represent the strategy they used. For example, Lehmann and Hasselhorn (2012) discuss the use of multiple strategies within trials, especially at longer list lengths (for example, using cumulative rehearsal for first 3 items then naming / once through for remainder). Lack of these types of combination options was a necessary limitation in this study due to the capacity and ability of participants to choose from several response options, but the topic could be an interesting one for future research.

Another concern regarding validity was the unintentional 'prompting' of the participants through asking which strategy they were using after each trial. The visual presentation of all the different strategies may have resulted in them 'trying out' an alternative method in the next trial, or simply result in them doing one depending on suggestibility. As a result, self-report is not without its limitations as it is challenging to control for this. There is also some evidence of predictive validity when using this method. The method was based on that of Poloczec et al. (2019) who found that the trial-by-trial self-reported strategies appeared to correlate with other measures, e.g., word length effect and also a self-paced measure which allowed children to proceed when ready, with the assumption that those taking longer were performing cumulative rehearsal internally. This gives some confidence that the data collected are accurate and representative. However, consideration of other methods of measuring strategy use may be desirable to provide more robust detail. It should also be noted that the strategy of self-report data collection was completed entirely after the main task to avoid this occurring and confounding the PSE data.

It seems feasible that children who are better recallers with higher memory span may have better awareness of the strategies they are using and as a result will report these more consistently or accurately, which could skew the findings to suggest that a certain type of strategy is selected more consistently at higher levels of recall when it could be a lack of awareness meaning it is reported less by the participants with lower levels of recall. A potential way to investigate this in more detail would have been to number the strategies with increasing scores for more 'advanced' strategies and sum these for each participant. These summed scores would give higher scores to participants using more complex rehearsal methods and could be used in analysis to identify any potential correlations with either a larger PSE or any of the additional measures. The potential of multi-level modelling to link the strategy choice to the child's performance was considered, but not carried through due to time restrictions on this particular project. However, a study looking into children's awareness and ability to use alternative strategies and the correlation between this and recall may an interesting aspect to consider for future work. It would be of interest clinically to understand if it could be targeted to support language comprehension outcomes indirectly through improving working memory (e.g., see Henry et al., 2022) or simply as a way as improving functional working memory in the classroom by training children to use a specific strategy more effectively.

A significant point for consideration in future work is that of the scoring method. Scoring of memory tasks such as these is complex and has led to some debate amongst researchers as to the most accurate way of measuring PSE and how to score it accurately. As described in section 9.2.1, Jarrold and colleagues propose that a proportional score is the most accurate way to determine presence and size of PSE, which accounts for difference in overall memory span and therefore detects a difference in recall between phonologically similar and dissimilar pictures even at a lower span level (Jarrold et al., 2015). This is particularly appropriate for this sample due to the low span level of the children with DLD.

The Span Score and Total Trials correct scores are perhaps of more relevance and more functional in a clinical setting than the proportional difference scores – they are immediately generated and they give an idea of the child's functional memory in terms of how many items or instructions a child could recall. The advantage of using a simple span score is that it can provide immediate information as to a child's memory span in relation to phonologically similar and dissimilar pictures – e.g., if their span score is 2.5 then feedback can be given to class teachers to limit key word instructions or lists to 2 items to ensure success. Looking at total trials correct can also be useful: some children pass trials only at the pass mark at each time (e.g., 4/6 at each span level) demonstrating poorer accuracy, whereas others get full marks on each trial but then suddenly none once the list goes above their span, which may also be useful information therapeutically to know. If the former, work could target accuracy at lower span levels, to improve overall success in working memory. Alternatively, some children may need support and strategies to develop their working memory increase in span length.

A strength of the methodology was that the memory task was devised to be completely non-verbal, so any effect of phonological similarity can only be attributed to phonological encoding occurring internally, compared to previous studies which have involved verbal elements at presentation of items lists or during recall (Al-Namlah et al., 2006; Jarrold et al., 2008; Jarrold & Hall, 2013; Palmer, 2000a). Robust background testing also meant the groups were well matched on age and non-verbal IQ as well as gender. Matching on non-verbal IQ reduces the potential of this being a confounding factor, as IQ is associated with working memory. Including two age groups allowed a consideration of developmental progress and comparison of different clinical groups with similar memory spans.

The memory span data showed extremely high split half reliability, and confirmation that no significant difference arose because of the medium used to administer the tasks. The sample sizes produced results with a large effect size and appropriate power when combining all TD and DLD groups - but the individual age groups were smaller than planned (because of COVID-19) so that future studies should look to include more children in each group.

9.7 Future research

The significant differences between groups of children with DLD and TD with respect to the size of their PSE raises further questions: at what age do these differences emerge, and do the abilities converge at some later point in development? As no differences were observed between the age groups in this thesis, it would be interesting to investigate strategy use in a younger age group such as 4-6 years, in older age groups (over 10 years) and perhaps over a larger variety of ages (using year groups rather than grouping children together) to track developmental changes in phonological encoding and choice of verbal rehearsal strategies: i.e., further investigating the 'overlapping waves' theory of strategic development. Using the same task in an older group also could confirm whether the PSE eventually 'catches up' with the TD group, or whether this difference in phonological encoding remains into adulthood. This would allow clearer understanding of the pattern of development of the PSE in children with DLD.

Matching span could also be considered to counteract the lower span levels of children with DLD. This involves the participants being presented with two separate lists and then asked if they matched or not. Requiring a lower processing load, it reduces the impact of floor effects when some children could recall only one item at a time independently and allows for longer lists (with more confusability) to be administered.

As well as including a wider age range, further work could recruit a larger group of participants to allow more extensive investigation into differences in recall strategies (or not) between phonologically similar and dissimilar pictures which were not examined in the current study. In future research it would be interesting to remove the option of 'complete' rehearsal, which was the least frequently selected choice, and consider instead simply verbal versus non-verbal rehearsal strategies, or the combination of strategies within trials. In the same vein, extension of this work could explore the link between performance levels and strategy used/reported. This study did not look specifically at whether the recall of each trial was correct or not within the self-report strategy task, and so further work could look at whether reported strategy use of 'higher level' rehearsal strategies correlates with better performance.

There is also the potential for collection of further observational data – for example, as mentioned, the researcher informally observed strategies being used (e.g., children tapping/bouncing or nodding as they rehearsed words; mouthing words silently; counting on fingers as pictures were shown and then counting them off as they recalled them) and often these did not correlate with what the child self-reported. For example, at times children selected 'cumulative rehearsal' even when the list length they had had to recall was only one item long; or they were observed to clearly the mouth the words but not identify this as 'naming. The way in which the data were collected meant it was not possible to include these observations in the analyses, but it would be an interesting area for extension work, to consider how best to collect and code these observations and see if the results of 'observed' strategy use follow the same patterns as those reported. This suggestion would also tie in with considering performance level without the experimenter 'suppressing' the use of overt private speech. As the current study looked specifically at inner speech, this was essential, but children with DLD appeared to find this more challenging. Clinically, it would be pertinent to understand if verbal rehearsal strategies are significantly different if overt rehearsal is permitted. Children with TD language have been shown to reduce their use of overt private speech as they develop, but children with DLD appear to make more use of self-talk over the age range of 6-10 years (Abdul Aziz et al., 2017).

9.8 Overall Summary and Conclusions

In recent years, much effort has been invested in raising awareness of Developmental Language Disorder, a condition that affects 7.5% of the population (Norbury et al., 2016). As well as increasing early identification and diagnosis to ensure intervention is offered to those who need it, more work is being done to invest in research into this heterogenous condition. The impact of DLD is far reaching: as well as affecting learning and being linked to dyslexia (Bishop & Snowling, 2004). DLD can be socially isolating (Botting et al., 2016), increases the risk of poor academic achievement (McKean et al., 2017) and is associated with behavioural and/or mental health problems and economic disadvantage (Winstanley et al., 2018)

Historically, variations in terminology and diagnostic criteria have meant that research carried out is not easily identifiable in searches (Bishop, 2014), or may not feel applicable to clinical caseloads. Much of what is known, and resulting therapeutic approaches, has been developed from practice and learning that speech and language therapists have acquired through working with this population (Bishop, 2010).

Interest in working memory difficulties, and their associated impact on language development, has involved studies into the differences between children with DLD and their typically developing peers, and identified significant differences between working memory ability, mainly focussed on verbal domain but also across all the systems of the working memory model. To date, no specific work has looked at the processes of phonological encoding and verbal rehearsal, skills that are essential for efficient phonological short-term memory, and also involved in language acquisition.

The current thesis aimed to address this gap in the evidence base in order to further our understanding of the 'inner speech' of children with DLD and begin to identify areas that could be targeted therapeutically in order to improve outcomes.

The main finding was that there was a consistent and substantial difference in the use of phonological encoding between children with and without DLD, evidenced by the significantly smaller PSE in children with DLD even when adjusting for lower overall memory span. This reduction in phonological encoding appears to be associated with a difference in self-reported use of verbal memory strategies – while children with DLD did use some verbal rehearsal strategies to aid recall, they did not consistently use cumulative rehearsal (the most 'sophisticated' method) as much as children with TD. This strategy adds more 'risk' of confusion between similar sounding items in the phonological store, leading to an increased phonological similarity effect in the TD group. Children with DLD reported using a variety of strategies to support their memory, but it seems possible that they do not select the most appropriate strategies for the task, are less able to use the strategies, or implement them with less efficacy compared with their TD peers. This contributes to poorer levels of memory span performance and a reduced PSE. Despite known differences between children with DLD and TD peers in other measures related to phonological encoding, no correlations were found in the current thesis between processing speed, reading or expressive vocabulary and the extent of the PSE in either group

Overall, the findings point towards the potential of practical, useful interventions that could improve the language outcomes of children with DLD, as well as laying foundation for potential further work looking at the development of phonological encoding and verbal rehearsal strategies and their role in working memory in children with DLD.

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Appendices

Appendix A Ethical Approval (including amendments due to COVID-19)

NHS
Health Research Authority

[redacted]

Email: hra.approval@nhs.net

09 November 2017

Dear Ms Moran

Letter of <u>HRA Approval</u>

Study title:	**The Impact of Developmental Language Disorder on Phonological Encoding**
IRAS project ID:	**224772**
REC reference:	**17/LO/1044**
Sponsor	**City University**

I am pleased to confirm that **<u>HRA Approval</u>** has been given for the above referenced study, on the basis described in the application form, protocol, supporting documentation and any clarifications noted in this letter.

Participation of NHS Organisations in England

The sponsor should now provide a copy of this letter to all participating NHS organisations in England.

Appendix B provides important information for sponsors and participating NHS organisations in England for arranging and confirming capacity and capability. **Please read *Appendix B* carefully**, in particular the following sections:

- *Participating NHS organisations in England* – this clarifies the types of participating organisations in the study and whether or not all organisations will be undertaking the same activities
- *Confirmation of capacity and capability* - this confirms whether or not each type of participating NHS organisation in England is expected to give formal confirmation of capacity and capability. Where formal confirmation is not expected, the section also provides details on the time limit given to participating organisations to opt out of the study, or request additional time, before their participation is assumed.
- *Allocation of responsibilities and rights are agreed and documented (4.1 of HRA assessment criteria)* - this provides detail on the form of agreement to be used in the study to confirm capacity and capability, where applicable.

Further information on funding, HR processes, and compliance with HRA criteria and standards is also provided.

It is critical that you involve both the research management function (e.g. R&D office) supporting each organisation and the local research team (where there is one) in setting up your study. Contact details

NHS
Health Research
Authority

[redacted]

21 July 2021

[redacted]

Dear Ms Moran

Study title: **The Impact of Developmental Language Disorder on Phonological Encoding**
REC reference: **17/LO/1044**
Amendment number: **224772 Amendment 4**
Amendment date: **08 June 2021**
IRAS project ID: **224772**

The above amendment was by the Sub-Committee in correspondence.

Ethical opinion

The members of the Committee taking part in the review gave a favourable ethical opinion of the amendment on the basis described in the notice of amendment form and supporting documentation.

Approved documents

The documents reviewed and approved at the meeting were:

Document	*Version*	*Date*
Completed Amendment Tool [224772 Amendment MORAN]	1	08 June 2021
Copies of advertisement materials for research participants [Recruitment on social media]	1	15 June 2021
Participant consent form [Consent of Qualtrics]	1	16 June 2021
Participant consent form [Parent Consent Form]	4	15 July 2021
Participant information sheet (PIS) [Information Sheet for Parents]	6	15 July 2021

Membership of the Committee

The members of the Committee who took part in the review are listed on the attached sheet.

Appendix B Participant Information and Consent Forms, Invitation letters and advertisements

a. *Participant Information Form*

NB Highlighted areas deleted as applicable for the group the potential participant would be included in

Inner Speech in children with Developmental Language Disorder (DLD)
Information for parents of children without/with DLD ('control'/'test' group – ages 6-7/9-10 years).

We would like to invite your child to take part in a research study. Before you decide whether you would like them to take part, it is important that you understand why the research is being done and what it would involve for you. Please take time to read the following information carefully and discuss it with others if you wish. Ask if there is anything that is not clear, or if you would like more information.

What is the purpose of the study?

This study will investigate how children with Developmental Language Disorder (DLD) use "internal (or inner) speech" in their short-term memory. This means looking at how children remember pictures – e.g., what they 'say' in their head when they see a picture.

The researcher will organise three Zoom sessions with your child, that we ask you are present for. The first will involve an assessment of their language and non-verbal reasoning skills; the second will be to carry out the short-term memory task and some quick tests of silent reading and picture naming (the latter will be recorded by the researcher), and the final will be to repeat the memory task and ask your child if they can describe how they remembered the pictures. Each session will last 30-45 minutes The visits are likely to occur within a month of each other. Breaks can be taken during the session whenever requested.

The whole project is expected to take three years to complete – this includes recruiting participants, collecting the data and writing up the report. Parents and carers will be sent information about the outcome of the study when it is completed.

Why has my child been invited?

Your child has been identified as meeting the criteria for this study as it is thought that:

- they do not/do have language difficulties;
- they are aged 9 or 10 years/ 6 or 7 years;
- they have had all their formal schooling in English;
- they do not have any known conditions that affect their learning.

If you feel your child does not meet any of the above criteria, or you are unsure if they do, please speak to the researcher using the contact details below.

Do I have to take part?

Participation in the project is voluntary, and you can choose not to participate in part or all of the project. You can withdraw at any stage of the project without being penalised or disadvantaged in any way. Your child can choose to stop at any time by telling the researcher they want to stop.

What will happen if I take part?

- The first session will act as a screening session to ensure that your child meets the inclusion criteria for the study - this includes some standard language tests and a non-verbal reasoning test. This session will take around 45 minutes in total and all tests are presented as fun games/puzzles.
- If your child meets the criteria for the study outlined above, they will complete a short memory task, looking at pictures and remembering which they saw, and then be asked to read some words, and name some pictures, to measure their speech rate and silent reading.
- At a third and final session, we will repeat the memory game and ask question to find out what strategies your child uses to remember. This will take 30-45 minutes in total.
- All sessions will be conducted over Zoom. Previously this project was carried out face-to-face – due to Covid-19 the tasks have now been moved online to avoid unnecessary risk to participants and researcher, in line with university recommendations and government guidelines.

What does my child have to do?

Your child will be shown different pictures, one at a time, and then asked to recall which pictures they were shown by clicking on the pictures in the correct order from a screen showing all the pictures. The researcher will ask your child how they tried to remember the pictures using illustrations of different remembering strategies (one of which is internal speech). Your child will also carry out some language and non-verbal reasoning games, and some quick tests of their speech rate, and silent reading ability.

What are the possible disadvantages and risks of taking part?

The tasks are very simple and unobtrusive - no risks are foreseen to your child in completing them, and most children find them very enjoyable.

What are the possible benefits of taking part?

It is hoped that information gained from this study will help us understand better how short-term memory works. We will also carry out this study with children who have language difficulties, so that we can see if there are important differences for children with these difficulties.

What will happen when the research study stops?
Information gathered will be anonymised and kept onsite at City, University of London in secure conditions for 10 years in line with the university's data protection policy.

How will my data be kept safe?
The Zoom session will be password protected with waiting room enabled, so the researcher will admit the participant into the Zoom 'room' and then lock the room, to ensure security is

maintained. The two short voice recordings will be made on a voice recorder by researcher and saved on secure hard drive (not in 'cloud' storage).

Will my taking part in the study be kept confidential?

Only the investigators will have access to results, which will be anonymised so no personal information will be included.
Consent forms will be stored at City, University of London, for the duration of the study (3 years), separately from the data collected. After the study is complete, the consent forms will be destroyed.
The anonymous data will be kept by the university for 10 years in line with their data protection policy.
All data will be stored in encrypted files and deleted after 10 years.

What will happen to results of the research study?

Results will be written up and submitted as part of a PhD. It is also hoped that some or all of the data may be published in a peer-reviewed journal and/or presented at a conference. All personal information about participants will be confidential and no identifying information will ever be included. If you wish to find out the results, you may give the investigator your contact details who can send a copy of the publication or summary of results.

What will happen if I don't want to carry on with the study?

If you, or your child, decide you no longer want to participate, you can withdraw at any time, the tasks will be stopped immediately, and your child's data permanently deleted.

What if there is a problem?

If you have any problems, concerns or questions about this study, you should ask to speak to a member of the research team. If you remain unhappy and wish to complain formally, you can do this through the University complaints procedure. To complain about the study, you need to phone 020 7040 3040. You can then ask to speak to the Secretary to Senate Research Ethics Committee and inform them that the name of the project is: **Inner Speech in Children with Language Difficulties**

You could also write to the Secretary at:
Anna Ramberg
Secretary to Senate Research Ethics Committee
Research Office, E214
City University London
Northampton Square
London
EC1V 0HB
Email: Anna.Ramberg.1@city.ac.uk

City University London holds insurance policies which apply to this study. If you feel you have been harmed or injured by taking part in this study you may be eligible to claim compensation. This does not affect your legal rights to seek compensation. If you are harmed due to someone's negligence, then you may have grounds for legal action.

Who has reviewed the study?

This study has been approved by City, University of London Language and Communication Science Proportionate Review Ethics Committee and the NHS Research and Ethics Committee [pending]

Further information and contact details

Researcher:
Abbie Moran
Abigail.moran.1@city.ac.uk

Supervisor:
Lucy Henry
lucy.henry.1@city.ac.uk
David Messer
David.messer@open.ac.uk

Thank you for taking the time to read this information sheet.

b. Parental Consent Form:

Study: *Inner Speech in Children with Developmental Language Disorder*

<table>
<tr><td></td><td></td><td>Please Initial:</td></tr>
<tr><td>1.</td><td>I have had the project explained to me, and I have read the participant information sheet (which has been emailed to me), which I may keep for my records.

I understand this will involve my child:
Undertaking a language assessment that looks at their understanding and use of language (e.g., vocabulary);
Undertaking a non-verbal ability assessment;
Completing some short language tasks that measure their picture naming speed; single word reading, silent reading and speech rate; and that these sections may be recorded using a voice recorder.
Completing three short picture recall tasks.
I have had the opportunity to ask questions; any I have asked have been answered to my satisfaction.</td><td></td></tr>
<tr><td>2.</td><td>I understand that the research will take place over Zoom
I understand that my email address will be used for the researcher to:
Send me a Zoom link for each session
Send a certificate of completion for my child after the final session</td><td></td></tr>
<tr><td>3.</td><td>This information will be held and processed for the following purpose(s):

In order to identify any differences in the use of internal or 'inner' speech between children with typically developing language and those with language disorders. The work will be collected, analysed and written up as a dissertation to be submitted as consideration towards a doctorate

I understand that any information I provide is confidential, and that no information that could lead to the identification of any individual will be disclosed in any reports on the project, or to any other party. No identifiable personal data will be published. The identifiable data will not be shared with any other organisation.</td><td></td></tr>
<tr><td>4.</td><td>I understand that my child's participation is voluntary, that I or they can choose not to participate in part or all of the project, and that I can withdraw my child at any stage of the project without them being penalized or disadvantaged in any way.</td><td></td></tr>
</table>

5.	I agree to City, University of London recording and processing this information about my child. I understand that this information will be used only for the purpose(s) set out in this statement and my consent is conditional on the University complying with its duties and obligations under the Data Protection Act 1998.	
6.	I agree for my child to take part in the above study.	

______________________ ______________________

Name of Child Date

____

Name of Parent

When completed, 1 copy for participant; 1 copy for researcher file.

____

Signature

____

Parent's email address

c. C. Invitation letters – control and test groups

Language and Communication Science
City University
London
EC1V 0HB

Dear Parent/Guardian,

I am a Speech and Language Therapist, conducting some research that is looking at how children with language difficulties use "internal speech" – e.g., what they 'say' in their head when they look at a picture.
I believe your child meets the criteria for the control/test group of participants required for this study and would therefore like to invite them to take part. This would mean that as they do not have language difficulties that they complete the study in order to compare them to a group of children who have language difficulties [delete for test group] Please see the attached information sheet for more details of these criteria, and the tasks involved.
If you and your child would like to be involved, or you would like more information about the study before giving consent, please call me on [redacted]

Many thanks,
[redacted]

Abbie Moran

d. Social Media Advertisement for recruitment

I'm a speech and language therapist and I'm currently at City, University of London, studying the impact of Developmental Language Disorder (DLD) on working memory development. DLD is the most common childhood disorder, affecting around but most people haven't heard of it...

I'm looking for children aged 6-10 years to take part in the research, which will involve some memory and language games (to be played over Zoom). Every child that completes the study will be entered into a prize draw to win one of two £50 Amazon vouchers!

If your child would be interested in taking part, please send me a message or email Abigail.moran.1@city.ac.uk ☺

Appendix C ***Table of results from statistical analyses comparing modality of task administration for Language, Non-verbal and Memory tasks***

Measure	Face to Face (n = 83)	Online (n = 49)	t-test outcome
CLS	73.83 (29.38)	31.10 (27.63)	$T(130) = -1.79, p = .076, d = 28.74.$
BAS3	47.47 (4.25)	46.84 (4.01)	$t(130) = 0.85, p = .400, d = 4.16$

Appendix D ***Results of Shapiro-Wilk (df) normality tests for Span Scores for each group***

Span Score	Phonologically Similar	Phonologically Dissimilar
6-7 years DLD (*n* = 40)	$W(41) = .971, p = .396$	$W(41) = .927, p = .013$
6-7 years TD (*n* = 29)	$W(28) = .031, p = .080$	$W(28) = .959, p = .364$
9-10 years DLD (*n* = 33)	$W(33) = .929, p = .042$	$W(33) = .934, p = .057$
9-10 years TD (*n* = 30)	$W(30) = .938, p = .098$	$W(30) = .914, p = .025$

Appendix E ***Results of Shapiro-Wilk (df) normality tests for Total Trials Correct scores for each group***

Total Trials Correct	Phonologically Similar	Phonologically Dissimilar
6-7 years DLD (*n* = 40)	$w(41) = .954, p = .273$	$W(41) = .957, p = .130$
6-7 years TD (*n* = 29)	$W(28) = .971, p = .273$	$W(28) = .958, p = .354$
9-10 years DLD (*n* = 33)	$W(33) = .936, p = .065$	$W(33) = .937, p = .069$
9-10 years TD (*n* = 30)	$W(30) = .903, p = .013$	$W(30) = .939, p = 105$

Appendix F ***Mean (SD), skewness and kurtosis and results of Shapiro-Wilk (df) normality calculations for proportional change scores for all groups with all participants included***

Proportional Change	Mean	Skewness	Kurtosis	Normality
All DLD (*n* = 73)	0.08 (0.46)	-1.95	5.77	*w* (74) = 0.85, *p* <.001
All TD (*n* = 59)	0.22 (0.26)	-1.32	4.40	*w* (58) = 0.91, *p* <.001
All 6-7 years (*n* = 69)	0.11 (0.45)	-2.38	7.88	*w* (69) = 0.79, *p* < .001
All 9-10 years (*n* = 63)	0.17 (.031)	-0.95	1.04	*w* (63) = 0.94, *p* = .005
6-7 years DLD (*n* = 40)	0.06 (0.53)	-2.14	5.76	*w* (41) = 0.79, *p* < .001
6-7 years TD (*n* = 29)	0.19 (0.29)	-1.67	4.85	*w* (28) = 0.87, *p* = .002
9-10 years DLD (*n* = 33)	0.12 (0.36)	-0.87	0.14	*w* (33) = 0.91, *p* = .009
9-10 years TD (*n* = 30)	0.24 (0.23)	-0.18	0.99	*w* (30) = 0.91, *p* = .657

Appendix G ***Friedman test results: Chi-squared (df) and probability of difference between selection of each strategy on the phonologically similar or dissimilar task for each clinical group (younger/older TD/DLD)***

	Naming	Cumulative	Complete	Visual	None
6-7 years DLD (*n* = 39)	$\chi^2(1) = .53$, $p = .465$	$\chi^2(1) = 1.29$, $p = .257$	$\chi^2(1) = .667$, $p = .414$	$\chi^2(1) = .50$, $p = .480$	$\chi^2(1) = 0.29$, $p = .590$
6-7 years TD (*n* = 28)	$\chi^2(1) = 1.29$, $p = .26$	$\chi^2(1) = 1.50$, $p = .221$	$\chi^2(1) = 2.91$, $p = .088$	$\chi^2(1) = 2.13$, $p = .144$	$\chi^2(1) = 0.04$, $p = .841$
9-10 years DLD (*n* = 33)	$\chi^2(1) = .36$, $p = .549$	$\chi^2(1) = .00$, $p = 1.00$	$\chi^2(1) = .18$, $p = .670$	$\chi^2(1) = .39$, $p = .532$	$\chi^2(1) = .391$, $p = .532$
9-10 years TD (*n* = 30)	$\chi^2(1) = .000$, $p = 1.00$	$\chi^2(1) = 1.82$, $p = .178$	$\chi^2(1) = 3.24$, $p = .072$	$\chi^2(1) = .18$, $p = .670$	$\chi^2(1) = 1.32$, $p = .251$

Appendix H ***Kruskal-Wallis statistic (df) and significance of frequency of choice of each strategy between age group for each of DLD/TD for combined picture types***

	Naming	Cumulative	Complete	Visual	None
DLD	$W(1) = 1.48$,	$W(1) = .01$,	$W(1) = .87$,	$W(1) = .14$,	$W(1) = .01$,
(n = 72)	$p = .224$	$p = .910$	$p = .350$	$p = .710$	$p = .919$
TD	$W(1) = .85$,	$W(1) = .71$,	$W(1) = 1.81$,	$W(1) = .60$,	$W(1) = .34$,
(n = 58)	$p = .356$	$p = .400$	$p = .179$	$p = .440$	$p = .558$