Speed of processing in Developmental Language Disorder (DLD): The case of real-time grammatical processing

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RESEARCH REPORT

Speed of processing in Developmental Language Disorder (DLD): The case of real-time grammatical processing

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Abstract

Background: Developmental Language Disorder (DLD) impacts various aspects of children's language abilities, including the processing of inflectional morphology. Prior research suggests that children with DLD exhibit deficits in processing speed and sensitivity to grammatical inflections, yet the relationship between these deficits remains unclear.

Aims: This study aimed to investigate the relationship between processing speed and sensitivity to inflectional morphology in children with DLD, focusing on their real-time processing abilities in response to regular past tense, third person singular, and regular plural inflections at different rates of sentence articulation.

Method: Eighteen children with DLD and 18 age-matched controls underwent word monitoring tasks that assessed sensitivity to grammaticality of inflections in sentences presented at normal and slow rates of articulation.

Results: At a normal rate of articulation, children with DLD demonstrated slower response times and reduced sensitivity to grammaticality across all inflections compared to controls. When the articulation rate was slowed, children with DLD showed improved sensitivity, particularly to regular plural and third person singular inflections, although deficits in processing the regular past tense persisted.

Conclusions: The findings suggest a significant relationship between processing speed and inflectional morphology sensitivity in children with DLD. Slower articulation rates improved grammatical sensitivity for certain inflections, highlighting the potential of tailored interventions that consider processing speed limitations. Persistent difficulties with the regular past tense inflection indicate the need for targeted support for children with DLD in this area.

KEYWORDS
developmental language disorder (DLD), grammatical deficits, inflections, speed of processing, word monitoring

WHAT THIS PAPER ADDS

What is already known on this subject

- Children with Developmental Language Disorder (DLD) have a wide range of language difficulties, but deficits in inflectional morphology are regarded as a 'hallmark' of the disorder. Children with DLD are also very likely to show deficits in speed of processing, although it is not known if a 'slowness to process' can causally explain the language difficulties these children experience.

What this study adds to existing knowledge

- When grammatical sensitivity was measured using an online real-time task, children with DLD showed widespread inflectional deficits when sentences were spoken at a normal conversational rate. When sentence articulation rate was slowed down, children with DLD were faster, more accurate and more sensitive to the grammaticality of constructions. However, deficits in the regular past tense remained persistent, even in this slow-rate condition.

What are the clinical implications of this work?

- This study has implications for clinical and educational practices that work with children with DLD to improve their language skills. The findings of this study show that when children with DLD are given more time to process incoming information, their grammatical skills significantly improve. This study also shows that deficits in the regular past tense are persistent, and children are likely need extensive and intensive support with this particular grammatical feature.

INTRODUCTION

Children with Developmental Language Disorder (DLD) experience difficulty using and understanding language, despite all other areas of development being 'typical' (Leonard, 2014). DLD affects approximately 7%–9% of English-speaking children (Norbury et al., 2016) with a ratio of roughly 1.33:1 boys to girls (Tomblin et al., 1997). Children with DLD have wide-ranging language difficulties including (but not limited to) issues with vocabulary learning, the use of wh- questions and grammar (Leonard, 2014). Although primarily a language disorder, the problems children with DLD experience often impact a wide range of social and educational domains (Bishop et al., 2017). These difficulties often affect a child right through their school life and into adulthood (Conti-Ramsden et al., 2002; Miller et al., 2008), even if the language difficulties improve (e.g., Vermeij et al., 2021).

DLD is a hugely heterogeneous disorder, with different patterns of difficulty depending on the native language of the child. For English-speaking children with DLD, grammatical morphology is significantly affected (Leonard, 2014; Rice & Wexler, 1996), with tense and agreement morphemes posing particular difficulty (Deevy & Leonard, 2018). Research consistently shows the regular past tense -ed inflection to be the most impaired morphological item for English-speaking children with DLD, even when considering their weaker language skills (e.g., Rice & Wexler, 1996; Rice et al., 2000). Although to a lesser extent than the regular past tense, errors in the third person singular -s inflection are also common in children with DLD (Rice & Wexler, 1996). In contrast, morphology that does not pertain to tense or agreement seems relatively unimpaired, such as the noun's regular plural -s inflection (see Leonard, 2014 for an extensive review of the morphological deficits in DLD).

Despite knowing a great deal about the difficulties children with DLD experience, the aetiology of the disorder remains unclear. A group of theories that attempt to explain the problems in DLD centre on a 'speed of information processing' deficit; these theories suggest that children with DLD struggle to process information in a time-effective manner. Whilst some theories within this category argue for specific issues with processing rapidly-presented auditory information (e.g., Tallal & Piercy, 1973), other theories suggest DLD can be explained by a more general 'slowness to process' (e.g., Kail, 1994). Supporting this, there is a substantial body of evidence to suggest that children with DLD are slow to perform all sorts of tasks, even those that have little to do with language. For instance, children with DLD show slower performance than their age-matched peers in tasks of peg moving and bead threading (Bishop et al., 2013), basic auditory reaction times (ARTs) (Nichols et al., 1995) and mental shape rotation (Schul et al., 2004). Children with DLD are also slower than their peers in measures of nonword learning and fast-mapping of linguistic items, especially when stimulus presentation rate is increased (Weismer & Hesketh, 1996). Picture naming speed is also impaired in DLD (Lahey et al., 2001), and Montgomery (2002) found that children with DLD were slower than age-matched controls when performing a lexical decision task. The slower processing of children with DLD remains to be the case not only when compared to chronological-age controls, but also to younger typically-developing children who have comparable language skills (e.g., Montgomery & Leonard, 2006). After reviewing the existing literature, Kail (1994) concluded that children with DLD were 33% slower than their peers to perform all constituent elements of any given task (linguistic or otherwise). Windsor and Hwang (1999) also reviewed existing data on DLD and processing speed, but reported a slowing rate of 18%. Additionally, Miller et al (2001) reported a 'generalised slowing' of approximately 14% in their experimental work using a sample of 9-year-old children with DLD, and this slowness to process continued into adolescence (Miller et al., 2006). All studies presented here managed to explain approximately 95% of the variance in task performance between the children with DLD and their typically-developing counterparts. Moreover, Park et al. (2015) reported that scores on tasks that measured speed of processing were moderately predictive of DLD status.

If the language deficits in DLD can be explained by I Generalised Slowing Hypothesis (see Kail, 1994), it stands to reason that children with DLD would have improved task performance when they are given more time to process incoming information. There is a small body of literature that supports this idea. For instance, Montgomery (2004) noted that when sentences were presented at a normal rate, children with DLD demonstrated poorer sentence comprehension skills than both age- and language-matched controls. When sentences were slowed down by 25%, the children with DLD performed as well as the language-matched group on sentence comprehension, however their performance remained below that of the age-matched group. In addition, Fazio (1998) found that children with DLD had serial recall abilities comparable to age-matched controls when items were presented at a slower rate, but worse than controls when items were presented at a normal speed. Finally, Montgomery (2005) noted that children with DLD showed significantly better real-time language performance when the stimuli articulation rate was slowed by 25%, as compared to a normal rate.

Collectively, the literature seems to suggest that speed of processing is a factor to be considered when assessing the aetiology of DLD. However, most of the research examining speed of processing in DLD does so in a somewhat broad-spectrum way. There is very little discussion examining whether the specific inflectional difficulties that are so characteristic of DLD can be attributed to deficits in speed of processing (see Leonard, 2014 for some analysis). In addition, there is no research to the author's knowledge that attempts to alleviate the inflectional difficulties in DLD by experimentally slowing stimulus presentation rate. Given that difficulty with inflectional morphology is one of the hallmark features of DLD (Bishop et al., 2017), it is important to assess how particular theoretical viewpoints can adequately explain this deficit, and if the difficulty can be alleviated.

If the specific inflectional difficulties in DLD can be attributed to deficits in speed of processing (e.g., Kail, 1994; Leonard, 2014), one must consider why some inflections are more impaired than others. That is, why might the plural -s inflection be less problematic for children with DLD than the third person singular -s, and how can speed of processing account for this? Whilst the Generalised Slowing Hypothesis appears to have merit, it fails to explain the differences in impairment across different morphological items.

One possibility is that the processing of sentence-embedded inflections is more time-dependent than other aspects of sentence processing. That is, inflections are brief in duration and so are highly time-dependent, and as a result may be the most likely to become impaired in the face of a speed of processing deficit. Thus, impairment in speed of processing (i.e., generalised slowing) may result in impaired inflectional awareness, leading to weak grammatical representations Miller et, al. (2001). Building on from this idea, Leonard and his colleagues have suggested an interaction between the phonetic properties of a morpheme and a child's processing speed ability in their 'Surface Hypothesis' to account for the differential impairment between various inflections. This 'hybrid' theory between the linguistic and cognitive domains argues that a child with DLD processes incoming information slower than their typically-developing peers, which leads to morphemes particularly brief in duration and low in phonetic substance to be passed over during sentence processing. Low phonetic substance is defined in terms of relative duration, but amplitude is also suggested to play a part. Such morphemes include consonant inflections such as past tense –ed and third person singular –s (Montgomery & Leonard, 2006). The Surface Hypothesis goes on to argue that a child with DLD is more likely to abandon processing of such brief and low phonetic substance morphemes, as they struggle to process real-time language effectively and need to 'skip' parts of a sentence to process its meaning in adequate time. To clarify, it is not suggested that children with DLD struggle to process low phonetic substance morphemes; rather these morphemes require more processing effort due to their phonological properties. Consequently, children with DLD may be susceptible to impaired processing of these morphemes, which could result in less well-developed representations.

Leonard's Surface Hypothesis is strengthened when we assess what inflections English-speaking children with DLD struggle with. In English, the regular past tense –ed and the third person singular –s inflections are particularly problematic for children with DLD. Both morphemes have relatively low phonetic substance as compared to the words surrounding them in a sentence. In contrast, the progressive inflection –ing is usually unimpaired in DLD, and it does have much more phonetic salience than the regular past tense and third person singular. Thus, despite being a verb inflection (which is notoriously difficult for children with DLD to master), its comparatively high phonetic saliency may protect it from becoming impaired in DLD.

To further examine the relationship between speed of processing and grammatical processing, this study aimed to explore whether speed of processing plays a role in the inflectional deficits of children with DLD. Specifically, this study examined whether slowing sentence presentation rate down would lead to improved sensitivity to inflections in a group of children with DLD, compared to when sentences were presented at a normal rate. Given the hierarchy of inflectional difficulty experienced by children with DLD, the regular past tense, third person singular and the regular plural inflections featured in this study. It was hypothesised that the inflectional sensitivity of children with DLD would be improved in the slow-rate condition compared to the normal-rate condition, in accordance with the findings of Montgomery (2004; 2005) and Fazio (1998). It is expected that the slow rate of presentation will give the children with DLD more time to complete all of the necessary processing steps required when listening to a speaker, and therefore afford them the time to process the sentence's inflections and their grammaticality.

Although there are no studies that examine individual inflections (instead, studies assess grammatical sensitivity on a more global scale), using the reasoning from the Surface Hypothesis and the slowing work of Montgomery (2004, 2005), it was hypothesised the children with DLD would show greater improvements in grammatical sensitivity for the noun inflection than the verb inflections, given its stronger comparative phonological saliency. That is, it is expected that the slower rate of presentation will enhance grammatical sensitivity to *all* inflections in the DLD group, and that processing will be especially facilitated for the noun inflection compared to the verb inflections. This is because, even when slowed, the noun inflection should continue to be more phonologically salient that the verb inflections due to naturally-occurring differences in acoustic and phonological properties.

METHOD

Participants

Children were recruited from two primary schools in Yorkshire, England, that both had language units paired with their mainstream site. These language units provided specialist support with language and communication to children in the form of activity-based group sessions several times a week. All children who attended the language units still completed most of their education in the attached mainstream primary school.

Eighteen children with DLD were included in this study (12 males and 6 females) with a mean age of 103.17 months (SD 4.00 months; range 98–110 months). Eighteen age-matched peers (AMPs) were also recruited (12 males, 6 females) with a mean age of 103.78 months (SD 3.78 months; range 97–110 months). Children with DLD scored below −1 SD of the mean on each of the three language measures: expressive vocabulary (expressive vocabulary subtest of the Clinical Evaluation of Language Fundamentals, Fourth Edition (CELF-IV); Semel et al., 2006), expressive grammar (word structures subtest of the CELF-IV, Semel et al., 2006) and receptive vocabulary (British Picture Vocabulary Scale, Third Edition (BPVS-3); Dunn & Dunn, 2009). Two children in the DLD group scored two points within 1SD of the mean on the BPVS, but they were still impaired on the remaining two language measures and so were included into the DLD group. AMPs achieved age-appropriate scores in these tests (i.e., within 1 SD of the mean). All 36 children in this study had age-appropriate nonverbal IQ scores (block design subtest of the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV); Wechsler, 2003). Parental report confirmed that no child had hearing loss, neurological impairment or other significant health or psychological difficulty. Scores on the cognitive and language measures are detailed in Table 1. Independent samples *t* tests showed that both groups differed significantly on all four standardised measures. Although the children with DLD performed significantly worse on the WISC-IV block design subtest than their AMPs, they still fell within 'typical' levels for DLD populations (see Bishop et al. (2017) for a discussion on nonverbal IQ cutoff scores in DLD).

Materials

Word monitoring tasks

This experiment used word monitoring tasks which are an effective way to assess participants' sensitivity to inflectional morphology in real-time (Montgomery & Leonard, 1998). In the task, a participant hears a target word, and then is required to press a response button as soon as they hear the given target embedded within a sentence. To assess inflectional sensitivity, the sentences are manipulated for grammaticality such that the target word is immediately preceded by a critical word that is either appropriately inflected or inappropriately uninflected (i.e., a bare stem where there should be an inflected form). A typical pattern of results shows slower reaction time (RTs) to the target word when the critical word is ungrammatical, compared to grammatical. For instance, RTs to the target 'football' are typically faster in the sentence 'last week the boy played football with his friends', as compared to the sentence 'last week the boy play football with his friends'. This difference in RTs indicates processing of the inflections; if there is no significant RT difference between grammatical and ungrammatical sentences, a lack of inflectional processing is implied (Montgomery & Leonard, 2006). In addition, RTs are generally slower to targets following a verb item, as compared to a noun item (e.g., Montgomery & Leonard, 1998). Experimental work has shown that the word monitoring task is effective in measuring general lexical processing (e.g., Montgomery & Leonard, 1998) and in assessing morpheme sensitivity in both children with DLD and those who are typically-developing (Montgomery & Leonard, 2006).

All stimuli sentences were in the active voice and of simple construction, generally assuming subject-verb-object order. Tense was indicated by the sentence beginning with either *yesterday, last week, every day, every week, today, this week;* the use of tense markers was counterbalanced throughout. Plurality was marked by a single digit preceding the noun (e.g., *the man saw two birds flying in the sky*). All critical verbs and nouns that were manipulated for grammaticality were monosyllabic, and it was ensured no

TABLE 1 Demographic data and mean scores (with standard deviations) on standardised tests for DLD and AMP Groups.

Group	*N*	Mean age in months	WISC-IV block design	CELF-IV expressive vocabulary	CELF-IV word structures	BPVS-3 receptive vocabulary
DLD	18	103.17 (4.00)	11.69 (0.77)	4.78 (0.88)	3.06 (1.39)	88.61 (9.43)
AMPs	18	103.78 (3.78)	12.89 (1.02)	8.78 (1.06)	9.83 (2.15)	117.44 (9.85)
t test			$t(34) = -3.741$, $p <$ 0.001	$t(34) = -11.051$, $p <$ 0.001	$t(34) = -10.017$, $p <$ 0.001	$t(34) = -8.974$, $p <$ 0.001

Notes: *t* test row represents significance of difference between the two groups. CELF-IV Expressive Vocabulary, CELF-IV Word Structures and WISC-IV Block Design scores are normalised scaled scores, with a mean of 10 and a SD of 3. BPVS scores are standardised to a mean of 100 and a SD of 15.

Abbreviations: AMP, age-matched peer; BPVS-3, British Picture Vocabulary Scale, Third Edition; CELF-IV, Clinical Evaluation of Language Fundamentals, Fourth Edition; DLD, developmental language disorder; WISC-IV, Wechsler Intelligence Scale for Children, Fourth Edition.

words within each sentence were acoustically similar to the target to limit the possibility of false alarm responses.

All stimuli were recorded by the experimenter (native English speaker) in a sound-proof room using a Sony ICD-UX71 digital voice recorder at a sample rate of 44 100 Hz. Sentences were spoken at a steady rate with a mean of 166 words per minute (an 'average' rate as defined by Pimsleur et al., 1977 cited in Tauroza & Allison, 1990). All sentence recordings were normalised to −3DB and any noise was removed from the sound files using Audacity (available at www.audacity.sourceforge.net). Each sound file began with a 1.5 s silence, after which the target word was presented. Another 1.5 s silence followed, before the sentence was presented that contained the target item. There were a final 2.5 s of silence at the end of the sentence, which was a 'safety net' for the children's RTs. That is, they may have needed some time after the sentence had finished being spoken to register the target word and respond appropriately. After this 2.5 s of end silence, the sound file ended. Pilot work showed that 2.5 s was a suitable response window, with observations noting that if children had not responded within this time, they had likely lost attention to the task (rather than it being the case that they were still processing the sentence).

There were two word monitoring task conditions used in this experiment; one where sentences were presented at a normal (baseline) speed and one where sentences were presented at 30% slower than baseline. The initial target word was always heard at a normal rate regardless of condition to ensure maximum comprehension. Sentence articulation rate was slowed down by 30% using PRAAT (Boersma, 2001). The PRAAT algorithm changed the temporal profile without affecting the spectral pattern so sentences sounded slow but natural. It was decided to change the rate only (and not the amplitude as well) because this study was explicitly exploring the speed of processing deficit in DLD, rather than, for example, testing the legitimacy of the Surface Hypothesis in explaining the grammatical deficits in DLD. In addition, if the stimuli had both rate slowed and amplitude enhanced, it would be difficult to establish which manipulation was responsible for any significant results. Finally, by just slowing the presentation rate, this study's methodology is more analogous to other work in this area (e.g., Mongomery, 2004, 2005) which also manipulated presentation rate only.

There were three inflections in this study: regular past tense *-ed*, regular third person singular *-s* and the regular plural *-s*. There were 16 sentences per inflection—8 grammatical and 8 ungrammatical—resulting in the word monitoring task having 48 sentences in total (a set A and set B were created to counterbalance for grammaticality). The critical words were homophones, such that they were either a verb or noun depending on sentence context. This helped to minimise phonological and articulatory confounds in the stimuli. In addition, the initial phoneme of the target word was the same for each verb-noun pair and in many cases, the target word was the same, as shown in the examples in Table 2.

Sentences were presented in a random order during the task. The position of the target word varied to prevent children from learning or predicting where the target word occurred. In addition, all sentences were controlled for on the basis of length and the number of syllables before the target word. Target words were controlled for on the basis of phonological neighbourhood density, number of phonemes and frequency (as defined by the Children's Printed Word Database, Masterson et al., 2010). Table 3 shows the statistical controls in place for the stimuli as a function of the critical words' class. It can be seen that there were no significant differences between stimuli items for any controlled variable.

The word class frequency of the critical words was also controlled, as far as practically possible. Given that the critical words were homophones, any frequency data derived from frequency databases would be inaccurate as such databases do not distinguish between word classes (word class frequency). For example, it is undetermined in frequency databases whether the given frequency count for the word /watch/ is for the noun version, the verb version, or both. It was important to control for this however as RTs to the target words may have been influenced by the preceding word's phonotactic probability (cf. Leonard, Davis & Deevy, 2007), and that may well have extended to word class frequency. For instance, upon hearing the word /run/, it is probable that one is more likely to think of it in the verb context (I can run) than the noun (I am going for a run). As such, RTs to a target word following /run/ are likely to be slower when it is used as a noun than a verb, as it is less frequently used in that context.

A pilot study was conducted to attempt to control for the word class frequency of the critical words in this experiment. In this pilot study, adult participants ($N = 10$) were given each of the critical words used in this experiment and asked to use it in a sentence with the first meaning that came to mind. This allowed some insight into whether the critical word was more likely to be thought of in a noun or verb context. When looking at the stimuli set as a whole, there was an even word class split: critical words were used as nouns 54% of the time, and verbs 46% of the time. This difference was not significant ($t(19) = -1.165$, $p > 0.05$). There were some critical words that were almost exclusively used as nouns or verbs in the pilot study, but the overall picture was even. Consequently, the critical words were controlled for on the basis of word class frequency as far as practically possible.

TABLE 2 Stimuli examples.

	Grammatical	Ungrammatical	Critical word, target word(s)
Past tense	Last week, the bus stopped outside the school	Last week, the bus stop outside the school	
Third person singular	Every day, the bus stops outside the school	Every day, the bus stop outside the school	Stop, outside
Plural	There are three bus stops outside the school	There are three bus stop outside the school	
Past tense	Yesterday, the man trained children to play football	Yesterday, the man train children to play football	Train, children/chugging
Third person singular	Every week, the man trains children to play football	Every week, the man train children to play football	
Plural	There were three trains chugging along the railway tracks	There were three train chugging along the railway tracks	

Note: Children heard the target word and were then required to press a response button as soon as they heard the word the sentence.

Basic auditory RT task

The main analyses of this study use RT data from the word monitoring task. Given that children with DLD often have slower RTs in all tasks, even those that have little to do with language (e.g., Lahey et al., 2001), the author wanted to ensure that basic auditory ART was controlled for. In the basic ART task, participants were asked to press the spacebar on a laptop as soon as they heard a beep. A total of 18 beeps were heard, each lasting 0.5 s. The beeps each followed a period of silence that varied randomly between 300 and 900 ms. The mean RT across all 18 trials was calculated for each child to establish their baseline ART.

Design

In addition to the group allocation (DLD, AMP), there were three manipulated independent variables in this experiment: grammaticality (grammatical, ungrammatical), inflection (past tense, third person singular, plural) and speed of sentence presentation (baseline, 30% slower). The dependent variable was the RTs (in milliseconds) to the target words in the word monitoring tasks.

This experiment used a within-subjects design for grammaticality, inflection and speed: All children experienced both grammaticality conditions, all three inflections and both speeds.

Procedure

This study was approved by a UK university ethics board and adhered to the standards and guidelines outlined in the BPS Ethical Code of Conduct.

Written opt-in consent was gained from each child's primary caregiver and their school; verbal assent was given by the child on each testing visit. Children were seen on a one-to-one basis in a quiet room of their school during normal school hours. Children wore noise-cancelling headphones for the ART task and the two word monitoring tasks, which were presented using the software E-Prime (Psychology Software Tools, Pittsburgh, PA).

Children were seen for two testing sessions, approximately one week apart. In the first testing session children completed the CELF-4 expressive vocabulary and word structures subtests, as well as the basic ART and one word monitoring task (either at a baseline or slow speed; the order was counterbalanced throughout data collection). In the second testing session children completed the BPVS-3, the WISC block design subtest and the remaining word monitoring task.

Each testing session lasted approximately one hour. Children were given short breaks between each testing element and were verbally rewarded throughout and reminded to 'keep listening'. Each word monitoring task started with a bank of 'dummy' sentences that the children practiced with until they understood the task demands. Most children needed just two or three practice trials before they were consistently pressing the response button as soon as they heard the target words. The experimenter asked the child to explain the task to them after these trials to ensure the children knew exactly what was expected of them. Once the child showed that they knew which button to press and when (i.e., as soon as the target word occurred and not before), and they could explain the task to the experimenter, the experimenter moved on to the test sentences.

TABLE 3 Details of the controls made for the target words in the sentences, as a function of the critical words' class.

Word class	Mean number of syllables per sentence (SD)	Mean number of syllables prior to target (SD)	Mean frequency of target word (SD)	Mean phonological neighbourhood density of target (SD)	Mean number of phonemes in target (SD)
Noun	11.25 (1.94)	5.15 (1.39)	263.85 (498.02)	3.05 (3.02)	4.95 (0.76)
Verb	11.05 (2.46)	4.6 (0.99)	314.75 (351.78)	4.9 (5.82)	4.4 (0.75)
noun-verb paired t test	$t(19) = .311, p > 0.05$	$t(19) = 1.718, p > 0.05$	$t(19) = 0.363, p > 0.05$	$t(19) = 0.1.464, p > 0.05$	$t(19) = -1.604, p > 0.05$

RESULTS

Data preparation

Before analysing the data, it was necessary to calculate children's RTs to the target words. For each sentence, the target word onset (in ms) within the sentence was noted. This was then subtracted from the participant's overall RT (in ms) to that sentence (as recorded by E-Prime) to establish the response speed to the sentence-embedded target word (method in accordance with Montgomery, 2002). For example, in the sentence *'every day the teacher whistles loudly at the end of playtime'*, the target word *loudly* appeared at 5213.54 ms. If a child's overall RT to the sentence was 7500.00 ms, their RT to the target '*loudly'* would be recorded as 2286.46 ms (7500 − 5213.54 ms). Given that this has the potential for human error, a second rater also recorded the target word onset. A Pearson's correlation was performed on the two raters' data to check the inter-rater reliability. Results showed a very strong, positive correlation between the target word onset figures for Raters 1 and 2 ($r(190) = 0.92$, $p < 0.001$) suggesting a high level of accuracy in the detection of the target word onset. In addition, the SDs for the RT scores were similar to those in the ART task, suggesting that this metric is a reliable one, with no major concerns around data variability.

Once all RTs had been calculated in this way, 'false' data points had to be addressed. Firstly, all responses made before the onset of the target word (i.e., negative RTs) were removed and classified as 'false alarm' responses. Next, all failures to respond (denoted by RTs of zero) were removed and treated as 'non-responses'. The sentences were spoken at a steady rate and there was a 2.5 s silence before the sound file ended. If children had not responded by the time the sound file ended, a non-response was recorded. Each child's mean RT as a function of grammaticality and word class was calculated using the remaining valid data points. This was then inserted into any blank cells derived as a result of this data verification to achieve a complete data set for each child (cf. Fazio, 1998). For instance, if a child's false alarm response was removed for an ungrammatical noun construction, that child's overall mean RT for valid ungrammatical noun trials was inserted into this cell. This process of removing false alarms and non-responses and replacing with a mean score is frequently used in studies using word monitoring tasks with children (e.g., Montgomery, 2005).

It is important to note that the RT data contained outliers and some skewness. However, the outliers were often individual children, rather than individual trial responses. That is, there were some children who were especially slow

TABLE 4 Mean basic auditory reaction time (and SD) in milliseconds.

Group	Basic auditory RT (SD)
DLD	410 (183)
AMP	369 (136)

Abbreviations: AMP, age-matched peer; DLD, developmental language disorder; RT, reaction time.

or especially fast in the experiment, but most children had a reasonably consistent RT profile within their own set of data. The removal of false-alarms and non-responses often cleaned up any within-participant outlying responses. In addition, data transformation with RT data can sometimes do more harm than good (see Feng et al., 2014 for a discussion on this), so for this reason, it was decided to use raw RT data for all participants, rather than remove individual outlying participants and/or transform the data.

Basic ART task

The mean scores for the basic ART task can be seen in Table 4. An independent-samples *t* test showed that although children with DLD responded to the basic auditory tones slower than their AMPs, this difference was not significant ($t(34) = 1.932, p > 0.05$). As such, ART was not used as a covariate in the analyses (cf. Montgomery, 2005).

Word monitoring task

Accuracy analyses

The number of false alarms and non-responses were collapsed into one 'error rate' variable (cf. Montgomery, 2005) for each group as a function of sentence articulation speed. The mean number of errors made can be seen in Table 5 (scores were out of a possible 48). A 2 (group) × 2 (speed) repeated-measures analysis of variance (ANOVA) showed main effects of speed ($F(1,34) = 7.597, p = 0.009$) and group ($F(1,34) = 19.882, p < 0.001$), as well as a significant speed*group interaction ($F(1,34) = 15.410$), $p < 0.001$). The interaction plot in Figure 1 suggests that error rates in the DLD group were significantly improved when sentence articulation rate was slowed down, compared to when they were presented at a normal rate. However, the error rates of the AMPs did not appear to show an improvement in the slow-rate condition. Paired-samples *t* tests confirmed this and are detailed in Table 5.

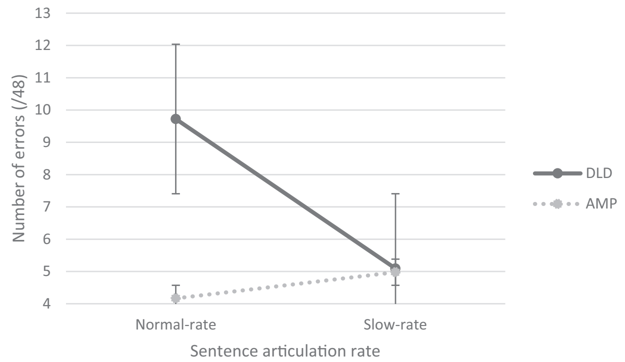

FIGURE 1 Interaction plot showing error rates in the DLD and AMP groups as a function of sentence articulation rate in the word monitoring tasks. Error bars represent standard error of the mean. Abbreviations: AMP, age-matched peer; DLD, developmental language disorder.

Inflectional sensitivity

The overall mean rection times to the sentence-embedded target words in the word monitoring tasks are presented in Table 6, separated out by language group, sentence articulation speed, grammaticality and inflection.

Normal-rate

A 2 (group: DLD, AMP) × 3 (inflection: past tense, third person, plural) × 2 (grammaticality: grammatical, ungrammatical) repeated-measures ANOVA was conducted on the RT data from the normal-rate word monitoring task. There were main effects of group ($F(1,34) = 28.751, p < 0.001$), inflection ($F(2,68) = 3.250, p = 0.045$) and grammaticality ($F(1,34) = 11.201, p = 0.002$), as well as a significant grammaticality*group interaction ($F(1,34) = 4.708, p = 0.037$). All other interactions were non-significant ($p > 0.05$).

To explore this further, separate 3 (inflection: past tense, third person, plural) × 2 (grammaticality: grammatical, ungrammatical) repeated-measures ANOVAs were carried out on the two language groups. For the DLD group, there were no main effects of inflection ($F(2,34) = 0.687, p > 0.05$) or grammaticality ($F(1,17) = 0.556, p > 0.05$), and the inflection*grammaticality interaction was non-significant ($F(2,34) = 0.033, p > 0.05$). For the AMP group, there were significant main effects of inflection ($F(2,34) = 3.799, p = 0.032$) and grammaticality ($F(1,17) = 20.205, p < 0.001$). The inflection*grammaticality interaction was non-significant ($F(2,34) = 2.970, p > 0.05$). This pattern of results can be seen in Figures 2 and 3.

It appears that when sentences were heard at a normal rate, children with DLD showed no sensitivity to the grammaticality in all three inflections under investigation

TABLE 5 Mean raw error rates (and standard deviations) in the word monitoring task, separated by language group and speed of sentence presentation.

	DLD	AMP
Normal-rate	9.7 (2.5)	4.2 (2.8)
Slow-rate	5.1 (3.0)	5.0 (3.0)
Paired-samples *t* test	t(17) = 5.334, *p* = <0.001	t(17) = 0.464, *p* = >0.05

Notes: scores have a maximum of 48.
Abbreviations: AMP, age-matched peer; DLD, developmental language disorder.

TABLE 6 Mean reaction times in the word monitoring task (in ms; SD in parentheses) as a function of language group, sentence articulation speed, inflection and grammaticality.

Language group	Speed	Inflection	Grammaticality	Reaction time (SD)
DLD	Normal-rate	Past tense	Grammatical	626 (163)
			Ungrammatical	637 (119)
		Third person	Grammatical	606 (209)
			Ungrammatical	622 (197)
		Plural	Grammatical	581 (176)
			Ungrammatical	603 (167)
	Slow-rate	Past tense	Grammatical	397 (125)
			Ungrammatical	403 (163)
		Third person	Grammatical	352 (105)
			Ungrammatical	414 (154)
		Plural	Grammatical	307 (89)
			Ungrammatical	378 (122)
AMP	Normal-rate	Past tense	Grammatical	424 (125)
			Ungrammatical	470 (111)
		Third person	Grammatical	391 (103)
			Ungrammatical	458 (128)
		Plural	Grammatical	323 (78)
			Ungrammatical	441 (84)
	Slow-rate	Past tense	Grammatical	458 (133)
			Ungrammatical	463 (175)
		Third person	Grammatical	432 (93)
			Ungrammatical	472 (190)
		Plural	Grammatical	405(161)
			Ungrammatical	454 (113)

Notes: Given the complexity of the design and the specific hypotheses related to speed of sentence articulation rate, analyses were conducted on each speed independently.
Abbreviations: AMP, age-matched peer; DLD, developmental language disorder.

in this study. That is, they responded with equal speed to all target words, regardless of inflection or grammaticality. However, the AMPs showed significantly faster RTs to targets embedded in grammatical sentences compared to targets embedded in ungrammatical sentences. In addition, the AMPs showed a hierarchy of RTs, such that RTs following verb items were slower than RTs following noun items. These findings are shown in Figures 2 and 3.

Slow-rate

A 2 (group: DLD, AMP) × 3 (inflection: past tense, third person, plural) × 2 (grammaticality: grammatical, ungrammatical) repeated-measures ANOVA was conducted on the RT data from the slow-rate word monitoring task. There were main effects of group ($F(1,34) = 4.523$, $p = 0.041$), inflection ($F(2,68) = 3.086$, $p = 0.049$) and grammati-

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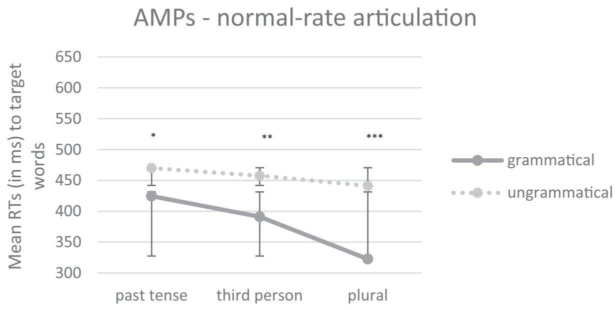

FIGURE 2 AMPs reaction times to the target words in the normal-rate word monitoring task, as a function of grammaticality and inflection. Please note: * denotes significance at $p < 0.05$; ** at $p < 0.01$ and *** at $p < 0.001$. Error bars represent standard error of the mean. Abbreviations: AMP, age-matched peer; RT, reaction time.

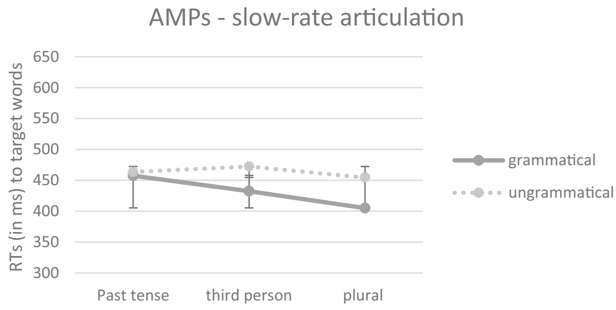

FIGURE 4 AMPs reaction times to the target words in the slow-rate word monitoring task, as a function of grammaticality and inflection. NB: *t* tests revealed non-significant differences between the grammatical and ungrammatical constructions for each inflection. Error bars represent standard error of the mean. Abbreviations: AMP, age-matched peer; RT, reaction time.

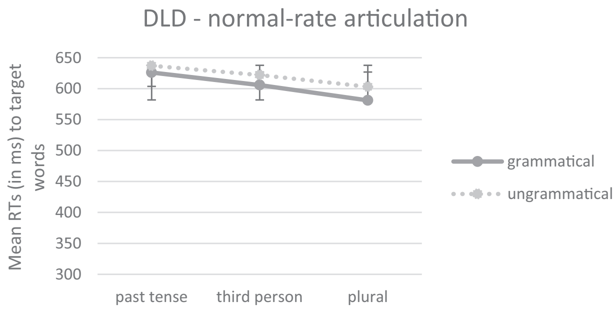

FIGURE 3 DLD reaction times to the target words in the normal-rate word monitoring task, as a function of grammaticality and inflection. NB: *t* tests revealed non-significant differences between the grammatical and ungrammatical constructions for each inflection. Error bars represent standard error of the mean. Abbreviations: DLD, developmental language disorder; RT, reaction time.

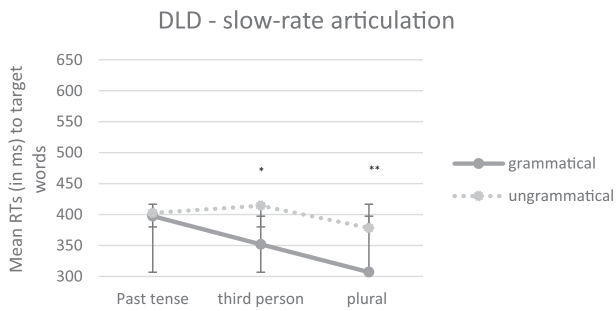

FIGURE 5 DLD reaction times to the target words in the slow-rate word monitoring task, as a function of grammaticality and inflection. NB: * denotes significance at $p < 0.05$; ** at $p < 0.01$. Error bars represent standard error of the mean. Abbreviations: DLD, developmental language disorder; RT, reaction time.

cality ($F(1,34) = 8.529$, $p = 0.006$). All interactions were non-significant ($p > 0.05$).

To mirror the analyses conducted on the normal-rate data and to explore the slow-rate data further, separate 3 (inflection: past tense, third person, plural) × 2 (grammaticality: grammatical, ungrammatical) repeated-measures ANOVAs were carried out on the two language groups. For the DLD group, there were significant main effects of inflection ($F(2,34) = 3.146$, $p = 0.048$) and grammaticality ($F(1,17) = 8.993$, $p = 0.008$). The inflection*grammaticality interaction was non-significant ($F(2,34) = 1.961$, $p > 0.05$). For the AMP group, there were no main effects of inflection ($F(2,34) = 0.648$, $p > 0.05$) or grammaticality ($F(1,17) = 2.119$, $p > 0.05$), and the inflection*grammaticality interaction was non-significant ($F(2,34) = 0.0345$, $p > 0.05$). This pattern of results can be seen in Figures 4 and 5.

When sentence articulation rate was slowed down, it seems that the children with DLD were much better at detecting the grammaticality of inflections, compared to their performance in the normal-rate articulation condition. The children with DLD also started to show a hierarchy of inflectional sensitivity, such that performance was better for nouns than verbs, as evidenced by RT discrepancies. However, sensitivity to the regular past tense inflection seemed to remain an area of significant difficulty for the children with DLD, despite the slower articulation rate. Interestingly, for the AMPs performance appeared to be worse in the slow-rate condition, compared to the normal-rate condition, and they were less sensitive to the grammaticality of all items.

DISCUSSION

The aim of this study was to examine the role that speed of processing plays in the inflectional deficits in children with DLD. To explore the aim, this study examined the real-time inflectional processing of children with DLD and age-matched controls when sentences were presented at normal-rate and slow-rate speeds. The findings from this study suggest that speed of processing does play some role in the inflectional processing of children with DLD. Specifically, this study found that when sentences were presented at a normal conversational rate of articulation, children with DLD did not show any sensitivity to the grammaticality of any inflection; they responded to all targets with equal speed, regardless of grammaticality or inflection type. This contrasts with the AMPs, who responded faster to targets in grammatical constructions than ungrammatical, and faster to targets following noun items than targets following verb items. However, when children were given more time to process incoming information by way of slowing sentence articulation rate by 30%, the children with DLD were more accurate and were more sensitive to grammaticality, compared to their performance in the normal-rate condition. In the slow-rate condition, children with DLD responded significantly quicker to targets in grammatical constructions than targets in ungrammatical constructions. In addition, the children with DLD began to show a hierarchy of inflectional sensitivity, with the regular noun plural showing the strongest performance and the regular past tense showing the poorest performance. The typically-developing children performed worse in the slow-rate condition in comparison to their performance in the normal-rate condition, which is interesting to note and will be discussed later in this section. Sensitivity to the grammaticality of all inflections was reduced in the slow-rate condition for the typically-developing children, bringing their performance to levels similar to that seen in the normal-rate for the DLD group.

The finding that children with DLD did not show any grammatical sensitivity to any inflection at the normal-rate speed is important to highlight. At this conversational rate of articulation, the children with DLD responded to target words with equal speed across all three inflections (regular past tense, third person singular, regular plural), regardless of whether the sentence was grammatical or ungrammatical. It is well-established in the literature that children with DLD show a hierarchy of inflectional difficulty, such that noun inflections are relatively unimpaired and verb inflections are problematic, with the regular past tense usually posing the most difficulty (see Conti-Ramsden, 2003 and Leonard, 2014 for reviews). This hierarchy of inflectional difficulty has been shown in a wide range of paradigms, including in naturalistic language samples (e.g., Rice & Oetting, 1993) and grammaticality judgement tasks (e.g., Hayiou-Thomas et al., 2004). Whilst previous studies have examined the real-time grammatical sensitivity of children with DLD using a word monitoring task (e.g., Montgomery & Leonard, 2006), they have usually done so in a more broad-spectrum way. That is, studies tend to collapse all inflections for analysis and look globally at sensitivity to grammatical versus ungrammatical constructions, rather than exploring specific inflections. The current study's findings suggest that real-time inflectional processing is impaired in both verb and noun morphology for children with DLD. This is supported by Leonard et al. (2009) who used a word monitoring task to assess the real-time sensitivity to the grammaticality of tense and agreement morphology in adolescents with DLD. Sentences were presented at a normal-rate and, like the current findings, Leonard et al (2009) also found substantial deficits in grammaticality sensitivity to inflectional morphology in their DLD sample when sentences were presented at a normal rate of articulation.

It could be argued that the inflectional difficulties in children with DLD are more widespread than the literature suggests, and that when we assess sensitivity to grammaticality in real-time we start to see deficits in morphemes that are often thought to be unimpaired in DLD (such as the regular plural -s) . However, it might also be that the time demands and complexities of the word monitoring task were simply too great for the children with DLD when sentences were presented at a normal rate. If we look at the slow-rate data, this seems like a plausible explanation. Here, when children with DLD were given more time to process the incoming information by slowing the speech signal down, they did show an improvement in overall grammatical sensitivity. This finding is comparable with other research in the field. For example, Montgomery and Leonard (2006) found that the word monitoring task performance of children with DLD was comparable to controls when sentences were slowed by 25%. In addition, Weismer and Hesketh (1996) found that the nonword learning of children with DLD was comparable to age-matched controls when they were presented at a slower-than-normal rate. Both studies found deficits when the sentences were presented at a normal rate. The current research also showed that slowing articulation rate down resulted in the DLD group showing the classic hierarchy of inflectional difficulty. That is, the children with DLD showed least sensitivity to the grammaticality of the regular past tense, and the most sensitivity to the grammaticality of the regular plural inflection. This supports the prediction that sensitivity to noun morphology would be facilitated more than sensitivity to verb morphology in the slow-rate condition. Paradigms that do show this classic hierarchy of impairment at a normal rate of articulation are usually 'offline' measures (such as the grammaticality judgement task) or expressive methods (such as naturalistic language samples), where the children are given more time to respond. In contrast, the word monitoring task is time-sensitive, which might explain the different findings between the present study and other work.

Interestingly, the AMP group showed impaired performance for grammatical sensitivity in the slow-rate condition, relative to the normal-rate condition. This is similar to the findings of Montgomery (2005), who also noted impaired performance on slow-rate stimuli for typically-developing children, relative to performance with normal-rate stimuli. On closer examination of the data, it appears that the performance of the AMPs in the slow-rate condition was similar to the performance of the DLD group in the normal-rate condition. As such, it appears that presentation rate has a different effect on the real-time inflectional processing of children with DLD than it does for typically-developing children. Whereas a slow-rate of presentation facilitated the inflectional sensitivity of children with DLD, it appeared to have the opposite effect and impair the performance of typically-developing children in this study.

The finding that presentation rate had contrasting effects between the two groups indicates a complex interplay between language and attention systems (e.g., Washburn & Putney, 2001). As Montgomery (2004) explains, to perform a word monitoring task a child must (1) allocate attentional resources to remember the target word and perform a speeded motor response as soon as they hear the target word, (2) encode the auditory signal into a meaningful linguistic representation and (3) sustain focussed attention for the duration of the task. The slow-rate condition may have reduced the task complexity for the DLD group by increasing stimulus exposure (e.g., Washburn & Putney, 2001), and allowed these children more time to complete the various attentional and perceptual stages of the word monitoring task (Montgomery, 2004). In contrast, it is possible that the slower rate of presentation may have *increased* the task complexity for the AMP group by placing greater demands on their attentional and memory processes. That is, the AMP children may have had to sustain attention, and hold the information in their memory, for longer in the slow-rate condition compared to the normal-rate condition. This might explain the poorer performance of the typically-developing group in the slow-rate condition, compared to the normal-rate condition. Indeed, Montgomery (2005) proposed a similar explanation for his finding that processing of slow-rate sentences was significantly hindered in typically-developing children, compared to a normal rate of sentence articulation.

Interestingly, slowing the speech signal down did not improve the regular past tense sensitivity of the children with DLD, relative to the normal speed condition, although it did for both the third person singular and regular plural inflections. This was not expected, and rejects the prediction made regarding performance on specific inflections in the slow-rate condition for children with DLD. This finding could be because the rate was not slow enough, although after examining the data there is no indication that sensitivity to the regular past tense was even beginning to improve, so this explanation is unlikely. Alternatively, it may be because this is one of the most difficult inflections for all children learning English to master. Given that children with DLD have a broad-spectrum difficulty with language acquisition, it may be that the impairment is so entrenched with this particular inflection that a simple short-term 'lightening of the load' may not be enough. Instead, children with DLD may require repeated exposure to slow-rate articulation, alongside help with learning to process language in a more time-effective manner before the deficit in the regular past tense starts to diminish.

So why is the regular past tense verb inflection particularly challenging for children? Chiat (2000) addresses this difficulty by making specific comparisons between verbs and nouns. She suggested that it may be difficulties with relative verb phonology which leads to the specific challenges with verbs. Chiat notes that verbs very rarely occur in isolation, as compared to nouns which are often presented as individual word forms to children, and may therefore be easier to learn. Alternatively, it may be difficulties with verb semantics and grammatical complexity that can account for the challenging nature of verbs. As Chiat (2000) highlights, verbs convey a great deal of information about specific events, from specific points-of-view, which focus on specific participants. They are also brief in duration and are highly dynamic. It is these complexities that are not present in nouns that may explain the disadvantage children have with verbs.

In addition to phonology and semantics, it may be acoustic stress patterns that can account for this difference in difficulty between verbs and nouns. Kelly and Bock (1988) examined 3000 English disyllabic nouns and 1000 English disyllabic verbs, and found that of the words with the stress on the first syllable, 90% were nouns. In contrast, of the words with the stress on the second syllable, 85% were verbs. Mattys and Samuel (2000) extended on from this research and suggested that the non-canonical stress pattern of verbs might explain why they are harder to acquire than nouns. They went on to argue that 'non-initial stress words do indeed require additional processing, as suggested by costs in processing time, accuracy and memory load for these words relative to initial-stress words' (p. 588 as cited in Black & Chiat, 2003).

The combination of the aforementioned conceptual-semantic, syntactic and/or phonological components of verbs make them particularly difficult to segment from running speech for all children, not just those with DLD. If we accept that children with DLD do indeed struggle with the speed of real-time speech, it seems plausible that verb morphology is the most susceptible to impairment because they are the most difficult to extract from an incoming speech signal.

The results of this experiment go some way in supporting the view that the specific inflectional difficulties in DLD are the result of a deficit in speed of processing. Overall word monitoring task RTs of children with DLD were slower than the typically-developing controls, as well as basic ARTs (although this difference was not significant). This indicates that there may be some level of ‘generalised slowing’ (e.g., Kail, 1994; Miller et al., 2001) in children with DLD. In addition, it was found that the inflectional sensitivity of children with DLD could be improved with regards to the third person singular and regular plural inflections when sentence presentation rate was slowed down. This gives some indication that the impairment in speed of processing might play a causal role in the inflectional difficulties in DLD. In relation to this, the findings of this study indicate a general over-arching relationship between speed of processing and inflectional processing in all children, not just those with DLD. There appears to be an important relationship between these two factors that needs to be explored more.

If we accept that the inflectional difficulties in children with DLD can be explained by generalised slowing, which results in impairments in the speed with which normal-rate language can be processed, we need to consider exactly how processing speed and inflectional morphology are related. In other words, why might a reduced speed of processing result in impaired morphological representations? The Surface Hypothesis argues that in DLD, a child’s reduced speed of processing interacts with the phonological properties of inflections to determine their affectedness, and this explanation goes some way to explaining the findings of this study. In addition, we need to consider how specific linguistic features of the inflections, such as grammatical complexity and semantic salience (following Slobin’s (1985) grammaticizability hierarchy), can interact with phonetic salience. For example, the 3rd person singular has features of both number and tense and depends on subject-verb agreement, whereas the plural concerns only number. In this study, when children with DLD processed slower-than-normal sentences, they were able to detect grammaticality in the two /s/ inflections but not in the past tense /ed/ inflection. Post-hoc acoustic analyses showed that the /ed/ was both quieter and shorter in duration than the two /s/ inflections, and it was therefore less phonologically salient. However, in terms of grammatical complexity and semantic salience—and indeed age of acquisition (Brown, 1973)—the two verb inflections are equivalent. This finding therefore lends support for the Surface Hypothesis: Speed of processing interacts with phonetic salience and grammaticizability.

Given the novelty of this finding and this type of detailed analysis of individual inflections, further research is needed for replication and validation purposes. In addition, a language-matched control group could further strengthen this research. By including this type of control group, conclusions could be drawn regarding the deficit in DLD relative to their general language weaknesses. That is, a language-matched sample would help answer the question of whether children with DLD are delayed, or deviant, with regards to their speed of processing and language skills. Additionally, a more detailed analysis of DLD samples are needed. DLD is a hugely heterogeneous group, and it is unlikely that a single explanation regarding the cause of inflectional difficulties in the disorder will fully encompass every member of the group. Indeed, whilst this research seems to indicate that speed of processing plays a central role in the morphological deficits in DLD (and perhaps morphological processing more generally in all children), this does not explain why there are a significant proportion of children with DLD who do not show any reduced processing speed (see Miller et al., 2001).

SUMMARY

To summarise, the aim of this study was to explore whether deficits in speed of processing might explain the inflectional impairments in children with DLD. To explore this aim, children with DLD and AMPs completed real-time, online measures of inflectional awareness at both normal-rate and slow-rate speeds. Sensitivity to the regular past tense -ed (verb), the third person singular -s (verb) and the regular plural -s (noun) was measured. The results showed that when sentences were heard at a normal, conversational rate of articulation, the children with DLD showed almost no sensitivity to the grammaticality of any inflection. This is at odds with previous literature using off-line methods which shows children with DLD demonstrate a hierarchy of inflectional difficulty (regular past tense < third person singular < regular plural). This suggests that children with DLD have significant difficulties with the speed with which normal-rate language is presented to them, and that they struggle to process grammaticality in real time. When sentence articulation rate was slowed down, the children with DLD were more sensitive to grammaticality, with the regular plural noun inflection showing strong improvements to levels similar to AMPs, followed by the third person singular verb inflection. Deficits in the regular past tense verb inflection persisted even in this slow-rate condition, which is likely to reflect the grammatical complexity of this particular morphological item.

This study makes a unique contribution to the literature on the inflectional deficits seen in DLD. Specifically, the findings of this research suggest that the inflectional difficulties experienced by children with DLD may be the consequence of a deficit in speed of processing. The data here show that when children with DLD are given more time to process incoming information, their real-time sensitivity to grammaticality is significantly improved. The data also show that deficits in the regular past tense are persistent, and that children with DLD need deeper support to help alleviate difficulties with this inflection.

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CONFLICT OF INTEREST STATEMENT

The author reports no conflicts of interest. The author alone is responsible for the content and writing of the paper.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are not publicly available. Data are, however, available from the authors upon reasonable request.

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