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Evidence of compensatory processing in adults with developmental language impairment: Testing the predictions of the procedural deficit hypothesis

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A R T I C L E I N F O

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A B S T R A C T

Background: The Procedural Deficit Hypothesis (PDH) proposes that individuals with primary developmental language impairment (DLI) have a deficient procedural memory, compromising their syntactic abilities. Individuals with DLI may compensate for procedural memory deficits by engaging declarative memory for syntactic tasks. Arguments are part of the lexicon whereas adjuncts rely on syntactic processing. As a result, individuals with DLI may have unusual difficulty processing adjuncts. Alternatively, processing for adjuncts may be typical for individuals with DLI but show frequency effects, indicating compensatory use of declarative memory.
Aims: Our goal was to test the predictions of the PDH by comparing argument and adjunct processing times for adults with and without DLI, and to seek evidence of compensatory use of declarative memory for adjunct processing. We further evaluated group performance on measures of visual procedural and declarative memory.
Methods and procedures: Forty-four adults, 21 with DLI, completed a self-paced listening task, a procedural memory task, and a declarative memory task. The self-paced listening task tracked the word-by-word processing time for sentences that included prepositional phrases acting as arguments or adjuncts. We used regression analysis to determine effects of group membership and argument or adjunct status on processing times. Correlation analyses evaluated relationships between argument and adjunct frequency on processing times by group.
Results and outcomes: We found no effect of group membership on the processing time for arguments and adjuncts in the self-paced listening task. Argument phrases were processed more easily by both groups. There were frequency effects for adjunct processing for the group with DLI, but not the group with typical language. We did not find the expected frequency effects for argument processing. The group with DLI also performed more poorly in both the procedural and declarative memory tasks. Secondary analyses found that

Abbreviations: DLI, developmental language impairment; DT, difference time; IRT, inter-response time; PART, Paired-Associate Recognition Task; PDH, procedural deficit hypothesis; TL, typical language; WPT, Weather Prediction Task.

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non-verbal intelligence was related to outcomes on the declarative memory but not the procedural memory task.

Conclusions and implications: We found mixed evidence on the predictions of the PDH. Adults with DLI may compensate for procedural memory deficits but it is unclear whether this depends on declarative memory or language processing experience. Compensatory processing is an important element of the language profile for adults with DLI.

Learning Outcomes: The readers will be able to describe how processing arguments and adjuncts in sentences may depend on different memory systems, and how adults with developmental language impairment may compensate for syntactic processing deficits.

1. Introduction

Children with developmental language impairment (DLI) as a primary disorder have significant difficulties learning and processing language, despite normal hearing and otherwise typical development. The disorder often persists into adolescence and adulthood (Aram, Ekelman, & Nation, 1984; Clegg, Hollis, Mawhood, & Rutter, 2005; Johnson et al., 1999; Stothard, Snowling, Bishop, Chipchase, & Kaplan, 1998).

Over the course of development, children with DLI appear to develop compensatory strategies that mitigate the impact of their language disorders for some uses of language. For example, adults with DLI may have only subtle difficulties in social conversation (Tomblin, Freese, & Records, 1992), despite ongoing significant language ability deficits in more demanding tasks. Most explanations of DLI, however, have not accounted for compensation (Thomas & Karmiloff-Smith, 2003). The Procedural Deficit Hypothesis (PDH) is one of the few theories of DLI that incorporates compensation (Ullman & Pierpont, 2005).

The PDH proposes that individuals with DLI have a deficit in procedural memory (Ullman & Pierpont, 2005), a system for learning and controlling cognitive and motor skills and habits (Purser & Jarrold, 2005). The procedural memory deficit is thought to underlie both grammatical and cognitive processing difficulties found in DLI. Receptive lexical knowledge, according to the theory, is relatively spared because it is supported by an intact declarative memory, a system for explicit recall of facts or events. Declarative memory is the basis for compensation according to the PDH. For language processes that depend on procedural memory in individuals with typical language, those with DLI engage declarative memory.

The PDH builds on a more general dual-mechanism theory for how language is processed, the Declarative/Procedural model (Ullman, 2001a; Ullman & Pierpont, 2005). This model asserts that grammatical aspects of language are computed using rules, whereas idiosyncratic aspects of language are stored in declarative memory. As a result, compensatory use of declarative memory results in frequency effects (Ullman, 2001a; Ullman & Pierpont, 2005). Processes that involve grammatical computation do not (Ullman, 2001a). If individuals with DLI compensate for grammatical deficits using declarative memory in cases where individuals with typical language use rule-based processing, there will be frequency effects for the DLI processing where there are none for typical language processing. Frequency effects have been found for regular past tense formation for individuals with DLI with none found for individuals with typical language (Ullman & Gopnik, 1999; Van der Lely & Ullman, 2001). Single-mechanism accounts of language learning challenge these findings by showing that declarative memory can support both grammatical and lexical learning (Freudenthal, Pine, Aguado-Orea, & Gobet, 2007; Plunkett & Juola, 1999). These accounts also show that frequency effects are more apparent at earlier stages of learning, and less apparent as structures are fully learned (Ellis & Schmidt, 1998).

1.1. Procedural and declarative memory in developmental language impairment

The evidence for the PDH is not conclusive. Studies supportive of the PDH have assessed the procedural memory of children with DLI (Kemeny & Lukacs, 2010; Lum, Gelgic, & Conti-Ramsden, 2010; Tomblin, Mainela-Arnold, & Zhang, 2007). Both adolescents (Tomblin et al., 2007) and children (Hsu & Bishop, 2014; Lum et al., 2010) with DLI have been shown to have poorer procedural memory ability than their typical language peers. In the case of the adolescents with DLI, the degree of procedural memory deficit was correlated with the participants' grammatical ability (Tomblin et al., 2007). Children with DLI showed procedural memory deficits in a study using the Weather Prediction Task (Kemeny & Lukacs, 2010), a probabilistic classification task that asks participants to make predictions based on co-occurrences within a set of cards. On a similar task with more trials, however, children with DLI showed similar learning to peers with typical language (Mayor-Dubois, Zesinger, Van der Linden, & Roulet-Perez, 2014). Adults with DLI perform more poorly on reinforcement learning tasks, consistent with the PDH (Lee & Tomblin, 2012).

Other researchers have not found deficits in procedural memory for children with DLI on less complex procedural learning tasks (Gabriel, Maillart, Guillaume, Stefaniak, & Meulemans, 2011). Gabriel et al. (2013), however, found procedural learning deficits when they administered a more complex task. Another study found no difference between children with and without DLI in initial procedural learning (Hedenius et al., 2011). There were differences in how much learning children with poor grammatical ability retained after a multi-day delay. The authors suggested that children with grammatical deficits may have difficulty in consolidating procedural learning over time, rather than in initial procedural learning. This study also found that deficits in procedural learning were not due to lower non-verbal intelligence. Finally, not all aspects of procedural memory are impaired in DLI: children with DLI are just as competent as peers with typical language on procedural learning that does not involve learning discrete sequential patterns (Hsu & Bishop, 2014).

Findings have also been mixed on whether children with DLI have a declarative memory deficit. Studies of verbal declarative memory have generally found deficits for individuals with DLI (Lum, Conti-Ramsden, Page, & Ullman, 2012; Lum et al., 2010; Riccio, Cash, & Cohen, 2007). For visual declarative memory tasks, children with DLI have been found to not differ from comparison children with typical language (Lum et al., 2012; Riccio et al., 2007) or differed only before controlling group differences in non-verbal intelligence (Lum et al., 2010). These studies leave open the question of whether deficits in developmental language impairment are confined to procedural memory. Ullman and Pierpont (2005) suggest that individuals with DLI have a procedural memory deficit, and may or may not have a declarative memory deficit. If, as the PDH suggests, individuals with DLI compensate using declarative memory, the theory is unclear on whether those with declarative memory deficits are less able to compensate, or if they may compensate with a resource other than declarative memory.

Beyond studies on procedural and declarative memory ability, there is other evidence that does not fit the profile of DLI proposed by the PDH. If declarative memory is intact, this should result in normal receptive lexical abilities in adults with DLI. Nonetheless, studies have found receptive lexical deficits in adults with DLI (Tomblin et al., 1992). Studies have also found deficits on implicit statistical learning in children with DLI, a skill involved in word learning (Evans, Saffran, & Robe-Torres, 2009). However, a recent study of word learning (McGregor et al., 2013) found that consolidating declarative memories of word meanings was a relative strength of adults with DLI. Encoding and retrieval of the phonological form of words, a skill relying on procedural memory according to PDH, was impaired.

1.2. Arguments and adjuncts in sentence processing

Less evidence has been presented for predictions of the PDH for language processing, particularly for language processes that were not well explored prior to the publication of the PDH. One such area is the processing of arguments and adjuncts by individuals with DLI. Processing arguments in sentences is supported by lexical knowledge (Ullman, 2001a) whereas processing adjuncts relies on syntactic processes (Boland & Boehm-Jernigan, 1998). This contrast enabled us to test predictions of the PDH by observing how argument and adjunct processing differed for adults with and without DLI.

The argument–adjunct distinction is widely accepted across theories of grammar (Quirk, Greenbaum, Leech, & Svartvik, 1985; Radford, 2004; Thompson, 1997). Arguments of a word provide the context for the word in a sentence. For example, the verb *hit* requires an agent to perform the action of hitting, and an object to be hit. Since these arguments are central to the meaning of a word (Quirk et al., 1985), they are considered part of the lexicon (Chomsky, 1970; Ullman, 2001a). Adjuncts are peripheral to the meaning of a word (Quirk et al., 1985), and so are not part of a word's lexical entry (Radford, 2004). To derive the meaning of an adjunct phrase requires combining the phrase with the word that it modifies, a syntactic process (Boland & Boehm-Jernigan, 1998). In the sentence *Bob hit the ball in the morning*, the adjunct phrase *in the morning* must be combined with the word *hit* to derive its meaning, here specifying the timing of the action.

1.3. Argument and adjunct processing in developmental language impairment

Little is known about argument and adjunct processing in adults with DLI. Studies of children with DLI, however, indicate that ability to process arguments is appropriate for their developmental level as measured by mean length of utterance (MLU) (Grela & Leonard, 2000; Thordardottir & Ellis Weismer, 2002). For example, children with DLI include obligated arguments at the same rate as typical language children who are matched for MLU (Thordardottir & Ellis Weismer, 2002). More complex argument structures do not appear to affect the ability of children with DLI to produce grammatical sentences any more than for MLU peers (Grela & Leonard, 2000), or in one case, also as compared to age-matched peers (Owen, 2010).

There is little evidence on the effects of adjunct status on children or adults with DLI. Two studies have found that children with DLI tend to omit adjunct phrases in situations where their typical peers would include such phrases (Fletcher & Garman, 1988; Johnston & Kamhi, 1984). The adjunct phrases were not strictly obligated by the grammar, but typical children responded to the pragmatics of the discourse by including more adjuncts.

1.4. Argument preference in sentence processing

Adults with typical language process arguments more easily than adjuncts (Schutze & Gibson, 1999). Schutze and Gibson (1999) specifically compared noun argument to verb adjunct processing because two sentence processing theories made alternate predictions for this contrast. The region of interest for the study was a prepositional phrase acting as either the argument of a noun, as in A, or the adjunct (optional modifier) of a verb, as in B:

A. The man expressed his interest *in a wallet* . . .
B. The man expressed his interest *in a hurry*. . .

Under one theory, the structural theory (Frazier, 1987), incorporating the adjunct prepositional phrase *in a hurry* in B should be preferred. Incorporating a verb adjunct phrase results in fewer nodes in the structure of the sentence, according to the phrase structure grammar employed by Clifton and colleagues (Clifton, Speer, & Abney, 1991) and reiterated by

Schutze & Gibson (1999). Fewer nodes should make the sentence easier to process. Under the second theory, the argument preference view (Schutze & Gibson, 1999), incorporating the phrase *in a wallet* in A should be preferred because it maximizes argument relations. The results supported the argument preference view.

The facilitating effect of arguments on typical adult sentence processing has been replicated but the basis for the argument advantage has been debated (Boland & Blodgett, 2006). One perspective is that the arguments of a word are stored as part of its lexical entry (Boland & Blodgett, 2006). When a word is encountered, its arguments are activated, easing the processing of arguments occurring later in the sentence. Since adjuncts are not part of the lexical entry, there is no similar easing for adjuncts. Instead, processing adjuncts relies on rule-based syntactic processing (Boland & Boehm-Jernigan, 1998). An alternate view is that arguments are easier to process because they occur with higher frequency (MacDonald, Pearlmutter, & Seidenberg, 1994). According to this view, both arguments and adjuncts are stored in the mental lexicon, and there is no fundamental difference between them, just a gradation of co-occurrence frequency.

Frequency effects should distinguish these views (Boland & Blodgett, 2006). The degree of easing for argument constituents should be related to the frequency of arguments appearing with their related nouns or verbs for both explanations. If however there are no frequency effects for adjunct processing this would support the first notion that adjuncts rely on syntactic processing (Boland & Boehm-Jernigan, 1998). Boland and Blodgett (2006) indeed found no significant correlation between reading times and adjunct phrase co-occurrence frequencies, whereas there were significant negative correlations between reading times and co-occurrence frequencies for the argument conditions. However, the variance of the argument co-occurrence frequencies in their materials was significantly larger than the variance of the adjunct co-occurrence frequencies. As a result, their null finding for adjuncts might have been the result of a restricted range of adjunct co-occurrence frequencies.

The effect size of the argument processing advantage in typical adults has not been reported (Boland & Blodgett, 2006; Schutze & Gibson, 1999). A study that compared sentence plausibility and argument status effects on processing time showed that plausibility effects outweighed argument status effects (Speer & Clifton, 1998), suggesting that the effect size of the argument processing advantage is more modest than some other known effects on sentence processing speed.

1.5. Argument preference and compensatory processing in adults with developmental language impairment

Based on the evidence from typical adults, adults with DLI should have little difficulty processing arguments, but adjuncts may present particular difficulties. If a word's arguments are part of its lexical entry, and activation of arguments relies on lexical processing, then adults with DLI should process arguments much like adults with typical language (Boland & Blodgett, 2006; Boland & Boehm-Jernigan, 1998). Adjunct processing relies on syntactic processing (Boland & Boehm-Jernigan, 1998), an area of difficulty for adults with DLI (Plante, Gomez, & Gerken, 2002; Poll, Betz, & Miller, 2010). Comparing adults with DLI to adults with typical language in their processing of arguments and adjuncts should show an argument advantage across groups and a group by argument status interaction resulting from the larger performance gap between arguments and adjuncts for the group with DLI.

Alternatively, adults with DLI may compensate for their deficient procedural memory by engaging declarative memory for processing adjuncts (Ullman & Pierpont, 2005). Compensation would enable adjunct processing for adults with DLI that is similar to that of adults with typical language. The group difference would be in the memory system engaged to perform the adjunct processing. Whereas the group with typical language would use a syntactic process (Boland & Blodgett, 2006; Boland & Boehm-Jernigan, 1998), the group with DLI might compensate with a declarative memory process (Ullman, 2001b; Ullman & Pierpont, 2005). Frequency effects would provide evidence for engagement of declarative memory (Ullman & Pierpont, 2005). A frequency effect would arise if the processing time is correlated with how often the adjunct co-occurs with the word it modifies. More frequently occurring adjuncts are more easily learned in declarative memory.

For adults with typical language, frequency effects for argument phrases and the absence of frequency effects for adjunct phrase processing would support the perspective that adjunct processing relies on syntactic ability (Boland & Blodgett, 2006). For adults with DLI, frequency effects for both argument and adjunct phrase processing would suggest compensatory reliance on declarative memory.

1.6. Assessing declarative memory

Ullman and Pierpont (2005) propose that compensation in DLI depends on a declarative memory that is more capable than the procedural memory. The ongoing compensatory reliance on declarative memory may result in normal or superior declarative memory ability in adults with DLI. A recent review shows that across five studies, children with DLI do not differ from children with typical language on tests of nonverbal declarative memory (Lum & Conti-Ramsden, 2013). Testing the PDH account of compensation in adults with DLI requires evidence of compensation in language processing and measures of the declarative and procedural memory ability (Thomas, 2005).

1.7. Design and research questions

The PDH predicts a double dissociation (Dunn & Kirsner, 2003). It suggests that procedural memory ability will affect syntactic processing but not lexical processing, whereas declarative memory affects lexical processing but not syntactic processing. This prediction and the PDH in general assume a degree of modularity for these memory systems. The validity of double dissociation designs and the modularity of cognitive systems have been questioned for developmental disorders (Karmiloff-Smith, Scerif, & Ansari, 2003). Those emphasizing a developmental perspective have argued that an impairment in one ability is very unlikely to have left another ability fully intact, and that modularity is a possible result of development but not consistent throughout development. Since the PDH assumes that procedural and declarative memory can have independent effects on language processing (Ullman & Pierpont, 2005), our research design is based on this assumption. We will consider the alternate perspective in our discussion.

We evaluated the PDH by measuring noun argument versus verb adjunct processing (following Schutze & Gibson 1999) in a self-paced listening task (Ferreira, Henderson, Anes, Weeks, & McFarlane, 1996). We also administered the Weather Prediction Task, a measure of procedural memory (Knowlton, Mangels, & Squire, 1996), and the Paired Associate Recognition Task, a measure of declarative memory (Reber, Knowlton, & Squire, 1996). Our research questions were the following:

1. Is the processing time difference between noun argument and verb adjunct phrases larger for adults with DLI than for adults with typical language? If adults with DLI rely on a deficient procedural memory system to process adjuncts, they should have more difficulty with such phrases than their typical language peers, resulting in a group by argument status interaction.
2. If adults with DLI do not differ from adults with typical language in their ability to process arguments and adjuncts, is there evidence that the group with DLI uses declarative memory to compensate for a procedural memory deficit? Differences in frequency effects would be evidence of compensation: significant correlations between adjunct processing times and adjunct co-occurrence frequencies for the group with DLI group with no such correlations for the group with typical language.
3. If there is evidence of compensation, is it based on intact declarative memory? If declarative memory is intact, the group with DLI should not differ from the group with typical language on the Paired Associate Recognition Task. At a minimum, the effect size of any group difference on the declarative memory task should be smaller than that found on the procedural memory task.

2. Materials and methods

2.1. Participants

Forty-four adults, age 18–27, participated in the study. We recruited participants from post-secondary schools in central Pennsylvania (22) and from a registry of participants in a longitudinal study of specific language impairment (SLI) in Iowa (22). For details on the initial recruitment of the Iowa participants, see Tomblin, Zhang, Buckwalter, & O'Brien, 2003. All participants were native English speakers with no history of hearing impairment, autism, cerebral palsy, serious neurological injury or intellectual disability.

Participants passed a pure tone hearing screening. Performance IQ (PIQ) for all participants was verified to be 80 or above. PIQ was calculated from the Picture Completion, Digit Symbol Coding, and Matrix Reasoning subtests of the Wechsler Adult Intelligence Scale, Third Edition (WAIS-III) (Wechsler, 1997) applying a method from Sattler and Ryan (1999).

Group membership (DLI, typical language) was determined by both history and testing. Individuals in the group with DLI reported a history of language difficulties (prior diagnosis of DLI (14), difficulties with reading comprehension (4) or spoken grammar (2)). Individuals qualifying for the group with typical language reported no history of language difficulties. Language testing followed a diagnostic procedure developed by Fidler, Plante and Vance (2011). This procedure was documented to classify young adults into language impaired and typical groups with the highest accuracy of procedures with documented classification accuracy. It employs a discriminant function to indicate whether a composite of three language scores indicates language impairment. It does not depend on specific cut points for each test.

The tests were a written spelling task from Fidler et al. (2011), Word Definitions from the Clinical Evaluation of Language Fundamentals, 4th Edition (CELF4) (Semel, Wiig, & Secord, 2003), and the Modified Token Test (de Renzi & Faglioni, 1978; Morice & McNicol, 1985) as outlined in Fidler et al. (2011) and Fidler, Plante and Vance (2013).

For the spelling task (Fidler et al., 2011), participants wrote 15 words from dictation. The score was the number correct. For Word Definitions (Semel et al., 2003), the investigator spoke a word, and participants provided a spoken definition. Definitions were scored as directed by the CELF4 manual, and standard scores were based on norms for 18–21 year olds, as specified by the Fidler et al. (2011) procedure. A second rater scored the 10% of the subtests and point-to-point agreement was 88%. In the Modified Token Test (de Renzi & Faglioni, 1978; Morice & McNicol, 1985), participants followed spoken directions. The investigator spoke the 44 sentence-level directions, and recorded whether the participant accurately followed the directions. The score was the number correct.

Scores were entered into the discriminant function from Fidler et al., 2011. Twenty-one participants with a positive output and a positive history of language difficulties were classified as language impaired. Twenty-three participants with a negative output and no reported history of language-learning difficulties were classified as typical language. A participant with a negative output who reported a history of language-learning difficulties was excluded from the study.

Table 1
Participant group characteristics.

Measure	Group with DLI (N = 21)		Group with TL (N = 23)	
	M	(*SD*)	*M*	(*SD*)
Age	22.4	(2.0)	21.5	(1.8)
Years of education	13.1	(1.1)	14.5	(0.9)
Performance IQ	97.5	(7.9)	113.7	(10.0)
Modified token test	70.4	(17.1)	91.3	(5.1)
Spelling	3.7	(2.2)	11.4	(1.9)
Word definitions	7.7	(3.3)	13.1	(1.5)

Notes. The performance IQ is calculated from the Picture Completion, Digit Symbol Coding, and Matrix Reasoning subtests of the Wechsler Adult Intelligence Scale III (Wechsler, 1997) using the approach from Sattler and Ryan (1999). The Modified Token Test (de Renzi & Faglioni, 1978; Morice & McNicol, 1985) scores are the group mean percentage correct. Spelling is the number of words spelled correctly of the 15 words presented from Fidler et al. (2011). Word Definitions is the group mean standard score for the subtest from the Clinical Evaluation of Language Fundamentals, 4th Edition (Semel et al., 2003).

Group means on the screening and classification measures are in Table 1. Thirteen of the participants with DLI and 19 with typical language were female. The age of the groups did not differ ($t(42) = 1.68$, $p = .10$). The groups did differ on years of education ($t(42) = 4.75$, $p < .001$) and PIQ ($t(44) = 5.92$, $p < .001$).

2.2. The sentence processing task

For the self-paced listening task (Ferreira et al., 1996), participants listened to sentences presented word by word on a computer, advancing through each sentence by pressing the space bar. At the end of the sentence, the participant heard a tone indicating the end of the sentence. Following the tone was a comprehension question or the next sentence. The computer captured the time spent listening to each sentence constituent.

The self-paced listening technique has produced results consistent with those of self-paced reading in typical adults (Ferreira et al., 1996) and typical children (Booth, MacWhinney, & Harasaki, 2000). Self-paced listening was selected for this study over self-paced reading to avoid potential confounds of reading disorders, which commonly overlap with DLI (Catts, Fey, Tomblin, & Zhang, 2002).

2.2.1. Sentence processing materials

Sixteen quadruplets of sentences were developed to compare the processing of arguments and adjuncts. Two conditions (noun arguments, verb adjuncts) followed Schutze and Gibson (1999) and enabled us to evaluate effects of argument preference as compared to structural simplicity. Adding two further conditions (noun adjuncts and verb arguments) allowed us to evaluate general argument versus adjunct processing, following Boland and Blodgett (2006). Examples of each condition are the following:

The physician...

suggested | a remedy | *to the traveler* | this morning (verb argument)
suggested | a remedy | *for the flu* | this morning (noun argument)
suggested | a remedy | *at the station* | this morning (verb adjunct)
suggested | a remedy | *with good evidence* | this morning (noun adjunct)

The italicized prepositional phrases were the critical regions of the sentences. We based the materials on Boland and Blodgett (2006), but revised them to ensure that conditions did not differ in word frequency, word familiarity and sentence plausibility. We also revised the materials so that the co-occurrence frequencies in the argument and adjunct conditions had similar variance.

To determine lemma frequencies of the verbs and direct object nouns, and co-occurrence frequencies across conditions, we used the spoken corpora of the Corpus of Contemporary American English (COCA) (Davies, 2009). Co-occurrence frequencies were determined by how often prepositional phrases like those in the study materials followed the relevant verbs or direct object nouns. Consider the sentence, *The police detective proposed an investigation to the captain right away*. After identifying sentences in the corpus containing forms of the verb *propose*, we selected sentences with the preposition *to* following *propose* within 9 words. We then screened the sentences for prepositional phrases playing the same role as in the experimental sentence. When more than 200 such sentences were identified, we determined the proportion of those sentences within the first 200 having the prepositional phrase playing the same role, and then applied that proportion to the total number of identified sentences. Forms of *propose* occurred in 3748 sentences, and in 291 cases it was followed by a prepositional phrase headed by *to* with the same sense as the experimental sentence, resulting in a co-occurrence probability of .078.

Lemma frequencies of the main verbs and direct object nouns did not differ across the four experimental conditions ($F(3,60) = .073$, $p = .974$). As in prior studies (Boland & Blodgett, 2006), the mean (*SD*) co-occurrence frequencies of the argument conditions (.139 (.066)) were larger than that of the adjunct conditions (.035 (.059)). The variance of the co-occurrence frequencies however, did not differ across conditions (Levene's test for equality of variances, $F(1, 62) = 1.72$, $p = .194$).

We conducted a series of norming studies with typical young adults, age 18–25. The 14 participants in each of the norming studies rated the familiarity of the main verbs, direct object nouns, and objects of the prepositional phrases in the materials. Participants rated words on a 7-point scale based on how often they had seen, used or heard the target words (de Groot, Dannenburg, & van Hell, 1994). Three norming studies were conducted, and 10% of the rated words overlapped between the studies. Correlations of ratings across studies were high (r's ranged from .75 to.94). Mean familiarity ratings from these studies did not differ across conditions for verbs ($F(1,62) = .00$, $p = 1.0$), direct object nouns ($F(1,62) = .442$, $p = .525$) or objects of prepositional phrases ($F(1,62) = 2.549$, $p = .115$).

For plausibility ratings, participants rated how likely the event described in the sentence was to occur using a 0–7 scale as in Boland and Blodgett (2006) and Schutze and Gibson (1999). Unlike these studies, sentences were presented as they appeared in the self-paced listening task rather than in passive form, and were presented in three randomized orders. Inter-rater agreement (intra-class correlation) was .82. Plausibility did not differ across the four experimental conditions ($F(3,60) = .69$, $p = .562$).

We confirmed the argument or adjunct status of the critical prepositional phrases using tests for argumenthood proposed by Schutze and Gibson (1999). For prepositional phrases to appear in argument conditions, they had to pass one or more of the six tests. For phrases to appear in adjunct conditions, they had to pass none of the tests of argumenthood.

2.2.2. Sentence processing task procedures

A male native speaker of Standard American English recorded the self-paced listening materials word-by-word by using a Marantz PMD660 digital recorder. Sound files were edited using Praat software (Boersma & Weenink, 2006) to eliminate periods of silence before and after the recorded word, and to normalize files to a common intensity level.

We presented sentences by computer with E-Prime 2.0 (Psychology Software Tools, 2009). Four lists of 16 experimental sentences were created, with one member from each quadruplet. Thirty-two filler sentences were added to the experimental sentences for lists of 48 sentences. The fillers varied in structure. Comprehension questions followed 18 of the 48 sentences. The questions were recorded as complete sentences, and required "yes" or "no" answers. Each of the four lists was presented in two pseudo-randomized orders. Lists were randomized by the Mix program (van Casteren & Davis, 2006), subject to the condition that no experimental sentence immediately followed a comprehension question.

Participants were instructed to listen to sentences and answer questions on some sentences. They were told to advance through the sentence by pressing the space bar, and to answer questions by pressing 1 for *yes* and 2 for *no*. They were encouraged to advance as quickly as possible without sacrificing accuracy.

Participants listened to six trial sentences, four with comprehension questions. After showing that they understood the task, participants proceeded to experimental sentences. The task was presented using headphones at a comfortable loudness.

2.2.3. Sentence processing task scoring

All participants in the study exceeded chance performance on comprehension questions. Two measures of processing time were calculated, difference times (DT) and adjusted listening times. The DT was calculated as in Ferreira and colleagues (1996). We calculated the inter-response time (IRT) as the duration from one space bar push to the next. IRTs by word were summed to arrive at IRTs by region for the analysis. The IRTs minus the sound file durations and file presentation latencies were the difference times (DT).

DTs more than 2.5 standard deviations from the mean by participant by region were eliminated as outliers. We also eliminated DTs that were not compatible with attending to the task. Participants heard the entire region at a DT of 0. At a DT of 2000 ms, the participant was likely not attending to the task, and so DTs beyond 2000 ms were eliminated. DTs less than −150 ms were also eliminated. These procedures eliminated 4.4% of the data from the prepositional phrase region, and 4.2% of the data from the end region of the sentence.

We also used the duration of the sound files as the predictor of listening times, and subtracted predicted listening times from the actual listening times for adjusted listening times (Booth et al., 2000). We completed by-participant regressions and calculated adjusted listening times after outlier elimination.

2.3. The procedural and declarative memory tasks

The Weather Prediction Task (WPT) was the measure of procedural memory for this study. The Paired Associate Recognition Task (PART) (Ragland, Gur, Deutsch, Censits, & Gur, 1995) was the measure of declarative memory.

2.3.1. The Weather Prediction Task

The WPT is a probabilistic classification task (Knowlton, Squire, & Gluck, 1994). Participants predict "rain" or "sun" based on four cards. We presented 14 card combinations. The association of each combination with a "sun" outcome was replicated from Reber et al. (1996). The probabilities of "rain" or "sun" were balanced across trials, and the range of probabilities was 0–1, with eight trials at a .50 probability of "sun."

The task was presented using E-Prime 2.0 (Psychology Software Tools, 2009). Card combinations were randomized by participant, subject to not presenting the same combination in consecutive trials. The participants made their prediction by pressing labeled buttons on a response box.

The cards for each trial remained on the computer screen for up to five seconds. After the participant's response, the outcome and feedback screen appeared for 1500 ms, followed by 500 ms before the appearance of the next card set. If the participant did not make a prediction within five seconds, a "no response" screen appeared, followed by the next trial.

The score for the WPT was the percentage of correct responses by block. There were five blocks of 10 trials each. A correct response was one aligned with the probability of the card set for the trial. If a card set was more often associated with "sun" and the participant selected "sun," that trial was correct. We eliminated trials with card sets equally associated with "sun" or "rain" before calculating the percentage correct for the block. We also dropped trials with no response.

Participants from the University of Iowa registry had participated in another study using the identical WPT six months prior to the present study. The WPT scores from the earlier study were used for those participants.

2.3.2. The Paired Associate Recognition Task

The PART asked participants to recall card pairings after a delay (Ragland et al., 1995). The cards consisted of geometric shapes varied in number and color. We presented a sequence of four card pairs, a target and a key card, for five seconds each, followed by a two minute delay. The participant was then asked which of four possible key cards were shown with each of the target cards. There were five blocks, each with a learning phase and a recall phase for four card pairs.

The task was presented using an E-Prime 2.0 (Psychology Software Tools, 2009) and instructions from Ragland and colleagues (1995). Participants completed three practice trials.

The percentage of key cards recalled correctly was the score for the PART. The computer recorded the responses to each trial, and the correct responses.

3. Results

Our first question was whether adults with DLI would be particularly slow to process adjuncts, phrases thought to rely on syntactic processing.

3.1. The sentence processing task

The mean difference times by group and by sentence region are presented in Fig. 1. The group with DLI appeared to have a narrower processing time gap between the noun argument and verb adjunct conditions than the group with typical language. Listening times by group and condition are presented in Table 2.

Sentence processing researchers have previously analyzed the processing time means by subject (*F1*) and by item (*F2*) in separate ANOVAs. This enabled them to infer whether the trends in the data generalize to the larger populations of individuals and linguistic materials (Baayen, Davidson & Bates, 2008). Psycholinguistic researchers have more recently advocated the use of mixed effects regression modeling instead of *F1* and *F2* analyses (Baayen et al., 2008; Locker, Hoffman & Bovaird, 2007). In mixed effects models, all participant responses for all experimental items are included in the analysis in one model, with appropriate adjustments for the repeated measures taken for each individual and item. Linear mixed effects modeling includes random effects for participants and items in a single model, enabling both adjustments for repeated measures and better control of the family-wise error rate than separate ANOVAs by participants and items (Baayen et al., 2008; Locker, Hoffman, & Bovaird, 2007). Given a lack of consensus on how to compute degrees of freedom in these models, we determined the statistical significance of a predictor by whether the absolute values of the *t*-statistic were greater than two, and by likelihood ratio tests (Arnon & Snider, 2010; Baayen et al., 2008). Likelihood ratio tests assess whether model fit statistics are significantly affected when a predictor of interest is excluded from the model (Tabachnick & Fidell, 2007).

To better meet assumptions of normality for regression modeling, we shifted and square-root transformed the difference times. The transformed difference times were entered into a linear mixed effects regression using the package *lme4* for the R computing environment (Bates & Maechler, 2010). The model included random intercepts for subjects and items, and fixed effects for argument status (noun arguments contrasted with verb adjuncts), group, and a group by argument status interaction. The fixed effect of argument status was significant ($b = -.83$, $SE = .30$, $t = 2.8$, $\chi^2(2) = 9.72$, $p = .007$). Noun arguments were processed faster than verb adjuncts. Group was not significant ($b = .83$, $SE = .60$, $t = 1.3$, $\chi^2(2) = 4.20$, $p = .122$). The group by noun argument interaction term was also not significant ($b = .42$, $SE = .27$, $t = 1.5$, $\chi^2(1) = 2.35$, $p = .12$). The gap between the noun argument and verb adjunct processing times trended smaller for the group with DLI, the opposite direction from that predicted by the PDH.

For the end region, none of the fixed effect predictors of processing time (group, noun argument versus verb adjunct status, or the group by argument status interaction) contributed to model fit (all *t*-values less than 2.0).

Models using adjusted listening times had a similar pattern as those based on difference times. For the prepositional phrase region, noun argument status, however, contributed to model fit only at the alpha = .06 level ($b = -48.7$, SE = 26.6, $t = 1.85$, $\chi^2(2) = 3.40$, $p = .06$). Neither group ($b = -2.2$, SE = 10.5, $t = 0.20$, $\chi^2(2) = 0.04$, $p = .84$) nor the group by noun argument interaction ($b = 9.1$, SE = 10.5, $t = 0.9$, $\chi^2(2) = 0.75$, $p = .39$) contributed to model fit. For the end region none of the fixed effect predictors contributed to model fit.

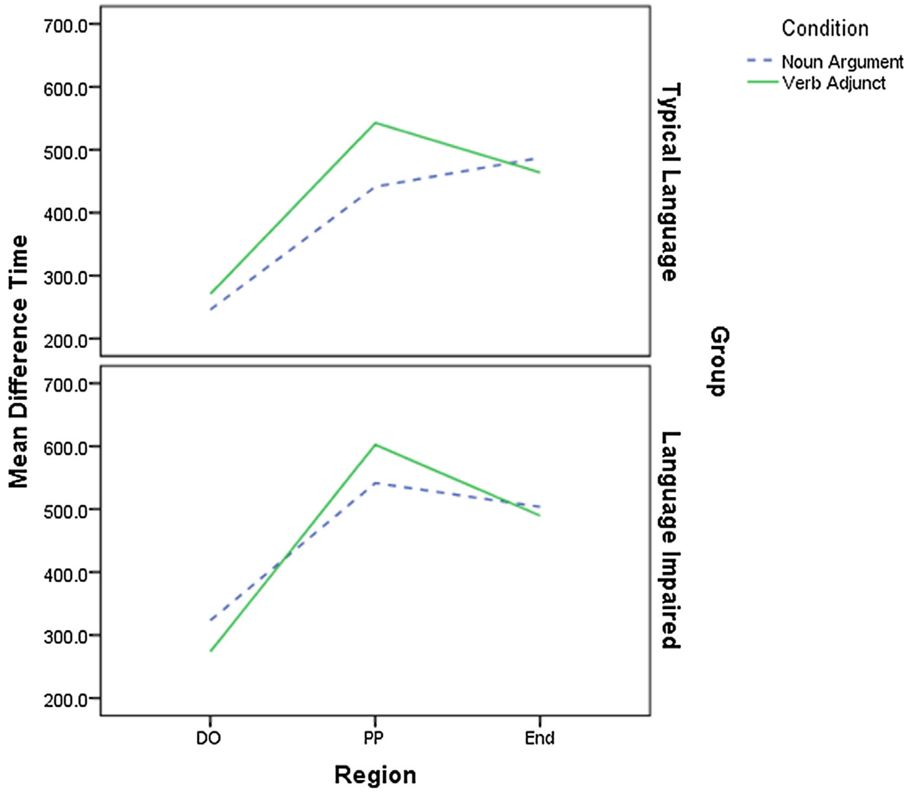

Fig. 1. Mean difference times by group, region, and condition. Difference times are total listening time for the sentence region less the time required to play the sound file.

Table 2
Mean listening times in milliseconds by group for the sentence processing task.

	DLI		Typical	
	N Argument[a]	V Adjunct[b]	N Argument[a]	V Adjunct[b]
Mean (*SD*) difference time				
Prepositional phrase region	542 (267)	602 (375)	441 (291)	543 (272)
End region	503 (358)	490 (330)	487 (390)	464 (332)
Mean (*SD*) adjusted listening time				
Prepositional phrase region	−45 (243)	26 (255)	−61 (225)	45 (205)
End region	−8 (243)	−16 (256)	47 (268)	19 (188)

[a] Noun argument.
[b] Verb adjunct.

The effect size for the overall noun argument versus verb adjunct processing difference was small ($d = 0.26$) based on Cohen (1988) (where small is 0.2, medium is 0.5, and large is 0.8). The argument versus adjunct contrast across all four conditions of the self-paced listening task was not significant. In both the prepositional phrase and end-of-sentence regions, none of the predictors contributed to model fit (all *t*-values less than 2.0). For adjusted listening times, coefficients for group ($b = 5.32$, $SE = 4.73$) and argument status ($b = -3.60$, $SE = 7.44$) were in the expected directions: the group with DLI tended toward slower processing, and arguments tended toward faster processing than adjuncts. The effect size of the argument versus adjunct difference was quite small ($d = 0.08$).

3.2. Frequency effects

Although we found evidence that argument status affects sentence processing, the effect did not differ by group. We next considered the alternative that the group with DLI processed adjunct phrases differently as indicated by frequency effects. For the noun argument and verb adjunct conditions, we evaluated whether there were correlations between adjusted listening times and the co-occurrence frequencies. Scatterplots of these relations are presented in Figs. 2 and 3. The relation did not appear to be linear, particularly for the noun argument condition. For the verb adjunct condition, the preponderance of the data was downward sloping. The PDH assumes that more frequent structures will be processed more quickly if

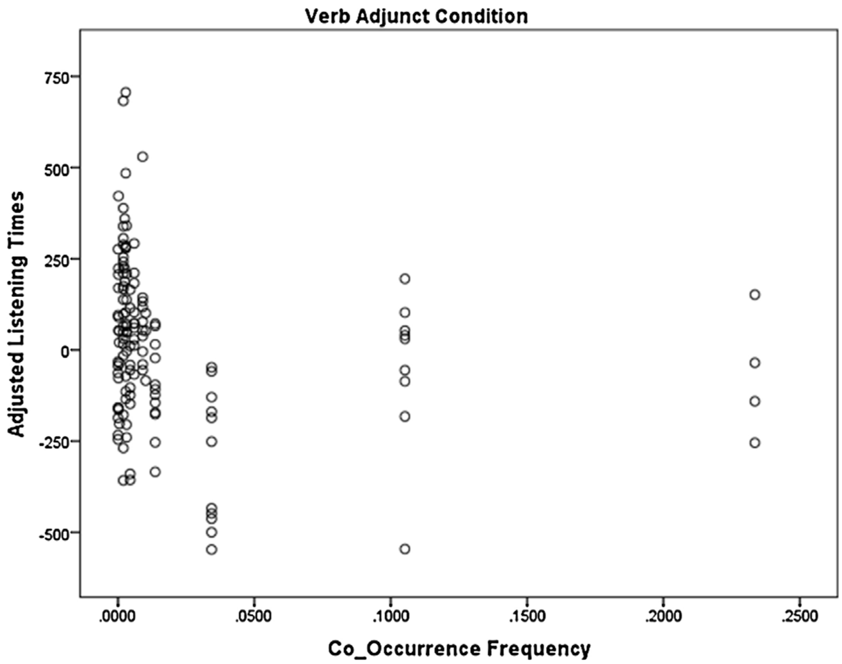

Fig. 2. Adjusted listening times by frequency of co-occurrence, verb adjuncts.

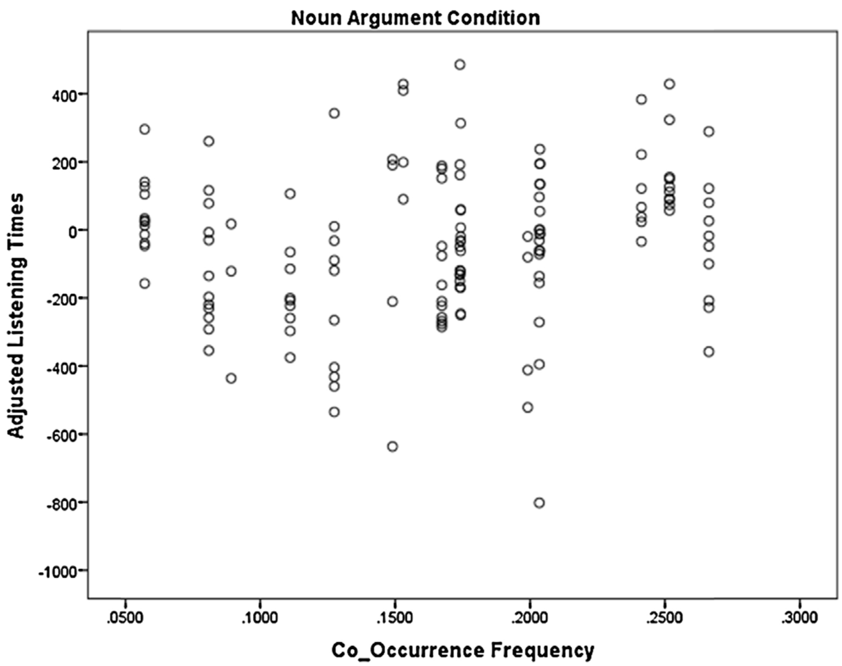

Fig. 3. Adjusted listening times by frequency of co-occurrence, noun arguments.

declarative memory is engaged, implying a negative linear correlation (Ullman, 2001b, 2006; Ullman & Pierpont, 2005). We therefore completed the planned correlational analysis as well as a regression to evaluate the non-linear relation between processing times and frequencies.

Ranks-based correlations between adjusted listening times and frequencies are presented in Table 3. There was a significant correlation in the verb adjunct condition for the group with DLI, with no significant correlation for the typical group. The correlation in the adjunct condition for the group with DLI was also significantly larger than for the group with typical language. Following Myers and Sirois (2006), we first calculated Pearson correlation coefficients ($r = -.23$ (DLI),

Table 3
Non-parametric correlations between prepositional phrase region adjusted listening times and the co-occurrence probabilities of the argument or adjunct phrases.

	p (co-occurrence)
Group with typical language	
Noun argument adjusted listening times	.306*
Verb adjunct adjusted listening times	−.115
Group with developmental language impairment	
Noun argument adjusted listening times	.133
Verb adjunct adjusted listening times	−.399**

* $p < .05$.
** $p < .01$.

$r = -.07$ (TL)) and then used these to compute a directional test based on the z statistic, a Fisher z transformation ($z = 1.91$ (one-tailed), $p = .03$). In the noun argument condition, there was a significant positive correlation in the group with typical language, and no significant correlation in the group with DLI. These correlations did not differ between groups ($r = .10$ (DLI), $r = .25$ (TL), $z = .97$, (one-tailed) $p = .166$).

Using difference times, the correlations followed a similar pattern as for adjusted listening times. For the group with DLI, the correlation in the adjunct condition was significant ($r_s = -.33$, $p < .01$), whereas it was not for the group with typical language ($r_s = -.17$, $p = .19$).

We next constructed a mixed effects regression model to evaluate the curvilinear relation between adjusted listening times and co-occurrence frequencies. The model included random intercepts for participants and items. We entered linear and quadratic (squared) co-occurrence frequency terms as fixed effect predictors of adjusted listening times. Significant quadratic terms would support a curvilinear relation. We log-transformed co-occurrence frequencies to better approximate normality. Note that the frequencies were small compared to the listening times, resulting in large regression coefficients. The model also included group, argument status and two-way interactions. The main effects of the linear ($b = -8476.4$, SE = 3848, $t = 2.20$, $\chi^2(1) = 4.91$, $p = .026$) and quadratic ($b = 84{,}443.4$, SE = 34,944.6, $t = 2.42$, $\chi^2(1) = 5.89$, $p = .015$) co-occurrence frequency terms were significant. Argument status was not significant ($t < 2.00$) as a main effect, but group was ($t = 2.84$). Interactions of group by argument status ($\beta = 64.4$, SE = 20.4, $t = 3.16$, $\chi^2(1) = 9.98$, $p = .002$), group by linear frequency status ($\beta = -4425.2$, SE = 1622.5, $t = 2.73$, $\chi^2(1) = 7.47$, $p = .006$) and group by quadratic frequency terms ($\beta = 31{,}672.6$, SE = 14,671.0, $t = 2.56$, $\chi^2(1) =$ $p = .030$) were significant. The model confirms that the relation between listening times and co-occurrence frequencies was non-linear, and that the groups responded differently to the argument status contrast. The relations of frequency to listening times also differed by group.

Taken together, the graphical, correlational and regression model evidence support the conclusion that the groups differed in how their listening times were influenced by frequency. The adjunct listening times for the group with DLI were more related to frequency than for the group with TL. The non-linear relation between frequency and listening times was not as predicted by the PDH or the Declarative/Procedural model of language processing on which it is based (Ullman & Pierpont, 2005).

3.3. The procedural and declarative memory tasks

Our third research question was whether declarative memory is a relative strength for adults with DLI, and may therefore serve as a basis for compensation.

3.3.1. The Weather Prediction Task

For the WPT, one participant from the typical group had a block 4 and 5 average of .25, more than 3 standard deviations from the typical group mean (*SD*) of .77 (.15). This participant's data was eliminated, leaving 22 participants in the group with typical language for this analysis. The proportion of correct predictions by block and by group is presented in Fig. 4. Both groups were near chance performance in the initial block and improved in later blocks. The group with typical language appeared to learn more quickly.

The arcsine transformed proportion correct for the WPT was entered into a 2 (group) by 5 (block) repeated measures ANOVA. There were main effects of block ($F(4{,}164) = 5.25$, $p = .001$, partial $\eta^2 = 113$) and group ($F(1{,}41) = 4.63$, $p = .037$, partial $\eta^2 = 101$), but the block by group interaction was not significant ($F(4{,}164) = 1.03$, $p = .395$, partial $\eta^2 = 02$). The group with DLI was less accurate in predicting weather outcomes from card clues, but both groups demonstrated improvement over the five blocks of the task.

3.3.2. The paired-associate recognition task

The PART was our measure of declarative memory. For the same set of participants included in the WPT analysis, the mean performance of both groups on the PART was above chance, with a mean (*SD*) of 66% (15%) for the group with DLI and 78% (17%) for the group with typical language.

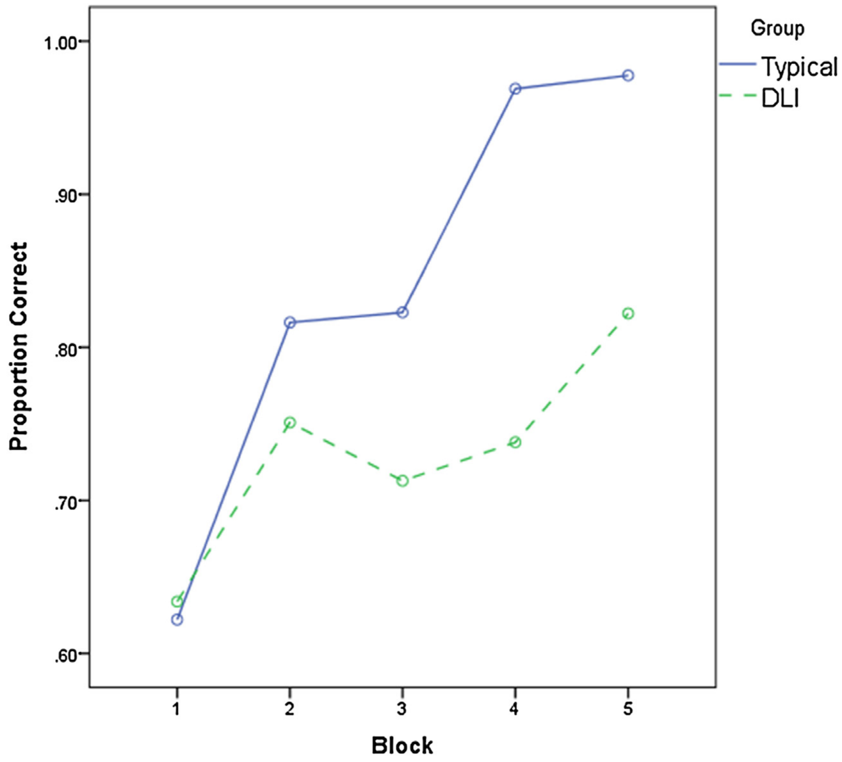

Fig. 4. Proportion correct by block and by group for the weather prediction task.

Table 4
Intercorrelations by group for performance IQ, language ability, sentence processing speed by condition, and procedural and declarative memory measures.

Measure	1	2	3	4	5	6	7	8	9	10
1. Perf IQ	–	−.51*	−.00	−.06	.22	.27	.04	.30	−.06	.12
2. Discrim	−.19	–	.00	.01	−.17	.14	.06	−.29	.21	−.09
3. Noun Arg	−.14	−.49*	–	.64**	−.03	−.10	−.04	.02	.03	.17
4. Verb Adj	−.42	−.25	.84**	–	−.07	−.26	−.01	.20	.10	−.00
5. PART	.55**	−.38	.52*	.19	–	−.03	.02	−.06	.06	.30
6. WPT 1	.29	−.20	.07	−.04	.36	–	.36	.20	.19	.10
7. WPT 2	.19	−.04	.08	−.03	.15	.45*	–	.61**	.41	.17
8. WPT 3	−.13	−.07	−.17	−.11	−.48*	−.23	.10	–	.34	−.11
9. WPT 4	.05	−.18	.23	.08	.09	−.07	.30	.17	–	.22
10. WPT 5	−.11	−.20	−.37	−.29	−.34	.00	−.20	.44*	−.36	–

Note. Intercorrelations for the group with typical language are presented above the diagonal, and those for the group with DLI are presented below the diagonal. Discrim = output of the discriminant function testing language ability based spelling, word definitions and sentence comprehension tasks; a positive score was associated with language impairment, a negative score with typical language. Noun Arg = the square-root transformed difference times for the prepositional phrase region in the noun argument condition, sentence processing task. Verb Adj = the square-root transformed difference times for the prepositional phrase region in the verb adjunct condition. PART = arcsine transformed Paired Associate Recognition Task. WPT is the arcsine transformed proportion correct on blocks 1–5 of the Weather Prediction Task.

* $p < .05$.

** $p < .01$

The proportion correct was arcsine transformed and entered into a one-way ANOVA. The mean for the group with DLI was smaller than that for the group with typical language, ($F(1,41) = 6.93$, $p = .01$, partial $\eta^2 = .145$).

There is evidence that some participants may use declarative processes to solve the WPT (Gluck, Shohamy, & Myers, 2002; Price, 2009). We therefore analyzed the correlation between PART scores and WPT performance by block for each group. The results are in Table 4. Most scores were uncorrelated, suggesting that the WPT and PART were indexing different abilities in the participants. For the group with DLI, there was a moderate but non-significant correlation for block one, suggesting possible declarative memory involvement in initial WPT performance. The one significant correlation in the group with DLI was negative, the opposite of what would be expected if participants relied on declarative memory for the WPT.

3.4. Effects of performance IQ differences

As has been found in several studies of adults with DLI, the mean PIQ for the group with DLI was significantly lower than the group with typical language (Lee & Tomblin, 2012; Rost & McGregor, 2012; Whitehouse, Line, Watt, & Bishop, 2009). Since lower PIQ relative to peers with typical language is characteristic of DLI (Plante, 1998), we did not match for PIQ or statistically control for PIQ differences in the primary analyses because such leveling would not be representative of the disorder (Dennis et al., 2009). It remains important, however, to determine whether the group differences we found are primarily effects of lower PIQ in the group with DLI. We took two approaches to better understand the effect of PIQ differences on our results.

We first calculated the correlations of our primary measures with PIQ, shown in Table 4. For the group with typical language, we found significant correlations for PIQ only with language ability (discriminant function output). For the group with DLI, PIQ correlated only with the declarative memory measure (PART). This may suggest that groups who differ less in PIQ may also differ less in their scores on the PART.

We next conducted a mediation analysis. Our goal was to understand if PIQ mediated, or accounted for, the relations between language ability and memory measures. We used a single mediator model (MacKinnon, 2008) involving three regressions. We found that PIQ was not a significant mediator of the association between procedural memory and language ability (mediated effect = .68, 95% *CI* [.54, −1.90]). The arcsine transformed fourth block score on the Weather Prediction Task (WPT4) was a significant predictor of the discriminant function output, our measure of language ability, indicating a direct effect of procedural memory on language ($b = -1.79$, $p = .04$). After entering PIQ as a second predictor, WPT4 fell just short of remaining a significant predictor (the direct effect was reduced, $b = -1.11$, $p = .06$) while PIQ was a significant predictor of language ability ($b = -.11$, $p < .001$). The WPT4 score was not a significant predictor of PIQ ($b = 6.12$, $p = .28$). The relation between procedural memory and language ability did not depend on PIQ.

We found that PIQ was, however, a significant mediator of the association between PART score and language (mediated effect 17.49, 95%*CI* [−3.07, −.57]). The transformed PART score predicted language ability (discriminant function output) indicating a direct effect of declarative memory on language ($b = -2.42$, $p = .01$). With PIQ added as a predictor, the PART was no longer a significant predictor of language ($b = -.60$, $p = .41$) but PIQ did predict language ability ($b = -.10$, $p < .001$). The PART score was a significant predictor of PIQ ($b = 17.49$, $p = .002$). The mediation analysis suggests that group differences in PIQ played a role in the group difference in declarative memory, but not in the group difference in procedural memory.[3]

As a whole, our secondary analyses suggest that the group difference in PIQ played a role in our findings of group differences on the PART, but less so on the WPT. There was little evidence of a role for PIQ in processing times for argument and adjunct phrases.

4. Discussion

This study set out to test predictions of the PDH for the processing of arguments and adjuncts in sentences. The PDH asserts that procedural memory is deficient in adults with DLI (Ullman & Pierpont, 2005). The PDH also rests on the Declarative/Procedural model of language (Ullman, 2001a; Ullman & Pierpont, 2005), which asserts syntactic processing relies on procedural memory. Adjunct processing is assumed to be syntactic by the PDH and some models of sentence processing (Boland & Boehm-Jernigan, 1998), suggesting that adults with DLI should have unusual difficulties with adjunct processing.

A distinctive feature of the PDH is its account of compensatory processing in DLI (Thomas, 2005). The theory suggests that compensation may enable adults with DLI to perform language tasks at levels similar to adults with typical language (Ullman & Pierpont, 2005). Furthermore, compensation is proposed to rely on an intact declarative memory. We will review how our findings accord with the PDH.

4.1. Procedural memory

Much of the research attention focused on the PDH has assessed procedural memory in children and adolescents with DLI (Gabriel et al., 2013; Hedenius et al., 2011; Lum & Conti-Ramsden, 2013; Tomblin et al., 2007). Our findings indicate that adults with DLI have a deficit in procedural learning, consistent with other findings for this population (Lee & Tomblin, 2012). Prior studies with children have found that probabilistic classification tasks, such as the WPT, have had inconsistent results, with group differences found for tasks with fewer trials, and more similar learning after more trials (Lum & Conti-Ramsden, 2013). Such findings suggest that individuals with DLI show procedural learning, but their learning requires more experience to reach the levels reached by peers with typical language. We found that adults with DLI improved their accuracy on the WPT over the course of the task.

[3] We also considered the relation of PIQ differences to our frequency effect findings by selecting two sub-groups of adults with DLI ($n = 18$) and typical language ($n = 18$) that differed less in PIQ. We again found frequency effects in the adjunct condition for the group with DLI, with none for the group with typical language. The complete analysis is available from the first author.

A finding related to the compensation claims of the PDH is whether performance on the procedural learning task, the WPT, involved explicit, declarative learning. There were no positive correlations between performance on the WPT and our declarative memory task, the PART (only the correlation between the first block of the WPT and PART was positive and moderately high ($r = .36$), but did not reach significance). This is contrary to evidence from typical young adults that the WPT involves declarative learning (Price, 2009). It also weakens the claim of the PDH that adults with DLI may rely on declarative memory to perform tasks that involve procedural memory in adults with typical language.

4.2. Adjunct processing deficits

According to the claims of the PDH, adults with DLI and a procedural memory deficit should have difficulties with syntactic processing, including adjunct processing (Boland & Boehm-Jernigan, 1998; Ullman & Pierpont, 2005). We did not find evidence of difficulties with adjunct processing for the group with DLI in an auditory sentence processing task. Both groups processed noun arguments more easily than verb adjuncts, in line with prior research that employed reading tasks (Boland & Blodgett, 2006; Schutze & Gibson, 1999). Evidence supporting the PDH would have shown a larger processing time gap in the group with DLI between arguments and adjuncts, resulting in a group by argument status interaction. Our evidence trended in the opposite direction, toward a smaller processing time gap for the group with DLI.

The absence of unusual difficulty processing adjuncts in the group with DLI has several potential explanations. It is possible that adjunct processing does not pose particular difficulties at any point in development for individuals with DLI, including adulthood. The counter-evidence for this view arises from studies of children with DLI, who appear to be less adept at processing adjunct forms (Fletcher & Garman, 1988; Schuele & Tolbert, 2001). The explanation of the PDH is that adults with DLI may develop the ability to compensate for their procedural memory deficits, enabling them to process adjuncts at a level similar to peers with typical language (Ullman & Pierpont, 2005).

4.3. Evidence of compensation

To evaluate the claim that adults with DLI compensate for their procedural memory deficits in language processing, we analyzed the relationship between sentence processing times and the co-occurrence frequencies of arguments and adjuncts with their related nouns or verbs. We found significant negative correlations between adjunct processing times and frequencies for the group with DLI, and no significant correlation for the group with typical language. This finding is supportive of the PDH, which suggests that processing times will be related to frequency when declarative memory is involved in the processing (Ullman, 2006; Ullman & Pierpont, 2005).

Looking beyond the frequency effects for verb adjuncts, however, the evidence is mixed for the compensation claims of the PDH. First, we expected to observe frequency effects for noun arguments. If argument processing is lexical, and therefore supported by declarative memory for both groups (Ullman, 2001a; Ullman & Pierpont, 2005), then we would expect negative correlations for argument processing times. We found that argument processing times declined as frequency increased for only a portion of the range of argument co-occurrence frequencies we tested. The relationship overall was unexpectedly curvilinear, with in an overall positive correlation between listening times and frequency that was significant for the group with typical language.

The mixed evidence on frequency effects suggests that the group with DLI may be processing adjuncts differently from the group with typical language, but it is not clear that it is because they are using declarative memory for both argument and adjunct processing whereas the group with typical language is engaging procedural memory for syntactic processing of adjuncts. The absence of adjunct frequency effects for adults with typical language, however, is consistent with the hypothesis that adjuncts are processed syntactically (Boland & Blodgett, 2006; Boland & Boehm-Jernigan, 1998). Our finding of faster processing times for noun arguments across groups is also consistent with the notion of lexically-supported argument processing. The positive correlations and curvilinear relation between processing time and frequency for arguments, however, do not fit the pattern predicted by the Declarative/Procedural model and PDH if arguments are processed with lexical support (Ullman, 2001a; Ullman & Pierpont, 2005).

Prior studies suggest a linear effect of frequency on processing time for lexical relations, with greater frequency associated with faster processing times (Boland & Blodgett, 2006). We considered whether the reversal of the expected trend for higher co-occurrence frequencies was due to sentence plausibility trends. Our sentence stimuli had both equivalent levels of plausibility across conditions and equivalent variances for co-occurrence frequencies in argument and adjunct conditions. These conditions provided the foundation for a valid analysis of the correlations between listening times and co-occurrence frequencies. In creating these conditions, we eliminated some argument sentences with the greatest co-occurrence frequencies, and sentences with lower co-occurrence frequency were substituted. This may have muted the argument advantage in our materials. Secondly, we presented sentences in the same form for both norming and self-paced listening, rather than presenting the sentences in passive form as was done in prior studies (Boland & Blodgett, 2006; Schutze & Gibson, 1999). It is unclear what effect this had on plausibility ratings. Given a stronger effect of plausibility than of argumenthood on sentence processing (Kennison, 2002), even a modest plausibility change across conditions could affect the results. Our experimental sentences in noun argument conditions with co-occurrence frequencies below .12 had mean plausibility ratings of 5.1 (on a 7 point scale) whereas sentences above .12 had mean plausibility ratings of 4.7. This within-condition difference was not statistically significant, however ($t(14) = .77$, $p = .45$), making a plausibility effect an unlikely explanation for the curvilinear trends in our data.

The PDH aligns with a categorical view of the argument-adjunct distinction, with arguments stored in the lexicon and adjuncts computed syntactically (Ullman & Pierpont, 2005). An alternative is that the groups responded differently to the frequencies of the adjunct and argument constituents, but using a common processing mechanism. Single-mechanism views have challenged the interpretation of frequency effects put forward by dual-mechanism proponents (Ellis, 2002). The presence or absence of frequency effects may result from earlier or later stages of associative learning rather than from different underlying processing mechanisms (Ellis, 2002; Ellis & Schmidt, 1998). Frequency effects are more easily detected in earlier stages of learning, by this view, than in later stages when learning has reached automaticity, resulting in ceiling effects. We may not have found frequency effects for the group with typical language because they are at an advanced stage of learning for adjunct processing. As indicated by this and other studies of procedural learning, the individuals with DLI may require more input to achieve learning (Lum & Conti-Ramsden, 2013). For adjuncts, they may be at an earlier stage of associative learning and so they have a more variable response based on the frequency of the construction. This may make frequency effects more detectable for the group with DLI.

A difficulty for the single-mechanism alternative is that the group with DLI achieved typical adjunct processing times. This appears inconsistent with being at an earlier stage of associative learning for adjuncts than typical peers if this implies slower sentence processing times as compared to later stages (Dick, Wulfeck, Krupa-Kwiatkowski, & Bates, 2004). It may be that adults with DLI were faster than adults with typical language for the most frequently-co-occurring adjuncts, enabling them to reach an equivalent overall processing time for the adjunct condition even as they were slower for less frequent adjuncts.

4.4. Declarative memory

Another evaluation of the compensation claims of the PDH is to assess the declarative memory of adults with DLI (Thomas, 2005; Ullman & Pierpont, 2005). A compensatory mechanism should result in better performance than the mechanism that requires compensation.

In our primary analyses, we found that the group with DLI showed a deficit in declarative memory as compared to the group with typical language. The group deficit for the PART, our declarative memory task, had a larger effect size than the group deficit for the WPT, our measure of procedural memory. This does not accord with the expectation from the PDH that individuals with DLI, particularly at later stages of development, may have intact or even superior declarative memory ability (Ullman & Pierpont, 2005). It is also unclear how a deficient declarative memory could be the basis for successful compensatory processing.

The use of declarative memory as a compensatory mechanism was also not supported by our correlational analyses. There were no significant positive correlations between the PART and the WPT at any block for the group with DLI. This indicates that the adults did not engage declarative memory in performance of the WPT, the procedural memory task. The PDH argues, however, that compensation develops over time (Ullman & Pierpont, 2005). Our participants had no experience with the WPT, so they may not have successfully engaged declarative memory to complete the task. There was also, however, no significant correlation between PART scores and verb adjunct processing times in the group with DLI, a task that involves ongoing experience with language where declarative memory could have been developed as a compensatory mechanism.

Studies with children have supported the claim of the PDH that those with DLI may have non-verbal declarative memory abilities similar to that of peers with typical language after accounting for non-verbal intelligence (Lum & Conti-Ramsden, 2013). We next consider the role of non-verbal intelligence differences in our findings.

4.5. Non-verbal intelligence group differences

We took two approaches to better understand the relationships between language, PIQ, declarative and procedural memory. In our correlational analysis, we found that PIQ correlated with PART scores but not to any block of the WPT for the group with DLI. The mediation analysis showed that PIQ was a significant mediator of the relationship between language ability and declarative memory, but not of the relationship between language and procedural memory. Taken together, it is clear that the level of declarative memory ability for adults with DLI is related to their level of PIQ. This would also suggest that compensatory ability, should it depend on declarative memory or PIQ, varies considerably among adults with DLI. Those with higher PIQ may more successfully compensate for procedural deficits. Our secondary analyses suggest that PIQ differences played a role in our finding of a group difference in declarative memory. Differences in procedural memory, however, do not appear to be primarily related to PIQ.

4.6. Evaluating the procedural deficit hypothesis

In evaluating the predictions of the PDH we found mixed evidence. Our findings are supportive of the contention of the PDH that individuals with DLI have a procedural memory deficit (Ullman & Pierpont, 2005). The presence of visual procedural memory deficits has been supported by several prior studies of children and adults (Gabriel et al., 2013; Kemeny & Lukacs, 2010; Lee & Tomblin, 2012; Tomblin et al., 2007), but the findings are not uniformly supportive (Gabriel et al., 2011; Hedenius et al., 2011) and results vary with the nature of the procedural learning task (Hsu & Bishop, 2014).

We did not find the expected manifestation of a procedural memory deficit in sentence processing, instead finding that the adjunct processing of adults with DLI did not differ from that of adults with typical language. This finding suggests that adults with DLI may have successfully compensated for their procedural deficits, at least in the verbal domain. Noun arguments were processed faster than verb adjuncts, and adults with typical language showed no frequency effects for adjuncts, both of which align with the view of adjuncts as reliant on syntactic processing (Boland & Blodgett, 2006; Schutze & Gibson, 1999). The gap in the evidence was the lack of the expected negative correlations—frequency effects—for noun argument processing in both groups. As a result, we did not find evidence that argument processing relied on declarative memory.

Frequency effects for adjunct processing for the group with DLI provided evidence of compensatory processing as predicted by the PDH (Ullman & Pierpont, 2005). Less supportive of the PDH was the evidence that visual declarative memory was impaired in adults with DLI. There was also no correlation between verb adjunct processing times and declarative memory for the group with DLI. The basis for compensation is unclear for adults with DLI.

For the group with DLI, frequency effects in the adjunct condition may indicate ongoing sensitivity to co-occurrence frequency that is not as pronounced in peers with typical language. They may have learned more common adjunct–verb pairings, and for these they may be as capable as or more capable than typical peers. But due to their need for more language experience to achieve similar levels of performance, they are slower for the least frequent verb–adjunct pairings. This argument is supported by studies on the nature of language learning and how frequency effects may be observed at some stages but less so as forms are fully learned (Ellis & Schmidt, 1998). Extending this thinking, adjunct processing for adults with DLI may rely on a procedural memory that requires more exposures to reach a given level of learning, compared to typical language peers. Or, it may rely on associative learning for both argument and adjunct processing, but again with a need for more experience for individuals with DLI to reach the levels of typical peers.

A further consideration for determining the basis for compensation in DLI is that online sentence processing may be independent of deficits identified in offline measures. This view is based on Caplan and Waters' (1999) argument on the relations of online sentence comprehension and working memory. Caplan and Waters found that working memory deficits affect the ability of individuals to use the output of sentence processing, but that working memory deficits do not affect the initial, automatic comprehension processes. Montgomery (2000) has found evidence for this online versus offline relation between online sentence processing and offline measures of working memory in children with DLI. This online versus offline distinction may also be true of declarative memory. Declarative memory may predict lexical abilities for offline language tasks—using the output of sentence processing. The immediate interpretation of a sentence may not rely on the same ability. Caplan and Waters (1999) argue that auditory online sentence processing is largely automatic given adults' extensive experience. The compensatory application of declarative memory in online sentence processing must be similarly automatic. In fact, Squire (1992) defines declarative memory as an explicit learning and memory system, whereas online sentence processing is argued to be an automatic process (Mitchell, 1995).

4.7. Conclusions

Our findings, and those of other studies of procedural and declarative memory in DLI, indicate that adults with DLI are likely to have deficits in at least some aspects of procedural learning. Many adults with DLI are also likely to have deficits in declarative memory, although this may depend on their non-verbal cognitive ability. Our evidence does not support clear links from deficits in procedural memory to deficits in processing adjuncts in sentences.

What is more evident from our data is that adults with DLI are able to process adjuncts and arguments at levels similar to peers with typical language. There is only limited evidence that adjuncts are problematic for children with DLI. Longitudinal evidence is required to understand the developmental progression of adjunct and argument processing in DLI. Our findings also support a difference in the response of adults with DLI to the frequency of adjuncts as compared to peers with typical language. This evidence aligns with the proposition of the PDH that compensatory processing may develop in individuals with DLI. It remains unclear if compensation relies on declarative memory or instead on acquiring additional experience with language structures. In either case, including a dynamic compensatory mechanism in the explanation of DLI is an important step toward understanding the nature of DLI at advanced stages of development (Thomas, 2005). Given the chronic nature of DLI for many adolescents and young adults (Aram et al., 1984; Johnson et al., 1999; Stothard et al., 1998), a better understanding of compensation may lead to better information on the prognosis of individuals with DLI, and new ways to help them build compensatory skills.

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Appendix A. Continuing education

Continuing education questions

1. Processing of adjunct phrases provides a test of the Procedural Deficit Hypothesis because...
   a. Adjunct phrases involve finiteness marking.
   b. Adjunct phrase processing is thought to require lexical knowledge.
   c. Adjunct phrase processing is thought to require syntactic ability.
   d. Adjunct phrase processing is thought to depend on declarative memory.
2. In the present study, adjunct processing in adults with DLI was found to have frequency effects. These effects relied on ...
   a. Correlations between adjunct processing times and adjunct phrase co-occurrence frequencies in spoken language corpora.
   b. Correlations between adjunct processing times and PIQ.
   c. Correlations between adjunct processing times and Weather Prediction Task accuracy.
   d. Correlations between adjunct processing times and syntactic ability.
3. The present study found that adults with DLI were generally slower processing argument phrases.
   a. True
   b. False
4. The analysis of the Weather Prediction Task in the present study showed a main effect of group. This suggests that...
   a. Adults with DLI have a deficit in declarative memory.
   b. Adults with DLI have a deficit in argument processing.
   c. Adults with DLI have a deficit in procedural memory.
   d. Adults with DLI have a deficit in adjunct processing.
5. Adults with DLI may compensate for their syntactic processing deficit by requiring more experience with language forms, or by engaging...
   a. Performance IQ
   b. Pragmatic ability
   c. Procedural memory
   d. Declarative memory

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