Nonword Repetition and Vocabulary Use in Toddlers

Stephanie F. Stokes, Catherine Moran, and Anjali George

Purpose: There is general consensus that the ability to repeat nonsense words is related to vocabulary size in young children, but there is considerable debate about the nature of the relationship and the mechanisms that underlie it. Research with adults has proposed a shared neural substrate for nonword repetition (NWR) and language production, but this has been little explored in children. Methods: This research explored the hypothesis that NWR and rapid word retrieval (the number of different words during conversation within 100 tokens, NDW100) are strongly related skills in young children who are described as late talkers (LTs). Results: In a sample of 92 typically developing 2-year-old children, a multiple regression to predict NWR from age, receptive vocabulary, expressive vocabulary, and NDW100, the predictors together accounted for 29.6% of the variance in NWR, $F(4,87) = 9.12, p < .001$, with receptive and expressive vocabulary being the significant predictors, $t = 2.47, p = .02; t = 2.99, p = .004$, respectively. However, in 21 LTs, only NDW100 was a significant predictor ($t = 2.66, p = .02$) of NWR, accounting for 52.9% of the variance in NWR, $F(1,19) = 21.30, p < .001$. Discussion: The results are interpreted as providing evidence for differences in the recruitment of the dorsal and ventral routes during psycholinguistic processing, between these 2 groups of children. Implications for therapy are discussed. Keywords: late talkers, lexical diversity, nonword repetition, vocabulary size

COMPELLING EVIDENCE supports a view that the ability to repeat nonsense words is related to vocabulary size in young children (e.g., Gathercole, 2006; Gathercole & Baddeley, 1990; Gathercole, Willis, Emslie, & Baddeley, 1992). Although there is general consensus regarding this view, there is considerable debate about the nature of the relationship and the mechanisms that underlie it.

One account of the relationship is that nonword repetition (NWR) is a measure of verbal short-term memory (VSTM) capacity, that is, how much information the phonological loop can process during an NWR task. Because learning new words (novel word forms) engages the phonological loop, new word learning is constrained by storage capacity. For instance, to learn new words, the phonological form of the word needs to be held long enough for successful processing (Gathercole, 2006). With repeated exposures to the new word, the word’s phonological representation is strengthened and maintained. Although other factors, such as sensory and output processes, impinge on word learning (Gathercole, 2006), this account suggests that VSTM capacity contributes to vocabulary acquisition.

According to the second account, NWR is conceptualized as a test of real-time phonological encoding—as opposed to storage capacity—with successful completion of the task dependent on the ability to access language information from long-term memory. Poor NWR ability is believed to reflect weakly established representations for phonological
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segments or syllables, or difficulty in accessing stored phonological representations for segments/syllables from long-term memory (e.g., Bowey, 1999; Metsala, 1999). According to this latter account, improvement in the ability to perform NWR tasks is a consequence of increases in vocabulary knowledge, the rationale being that with gains in vocabulary knowledge comes greater specification of phonological representations, which facilitates NWR performance. The two accounts differ on the direction of the relationship between NWR and vocabulary skills.

Evidence refuting the former account comes from a longitudinal study of the NWR and receptive vocabulary skills of 193 Norwegian-speaking children from 4 to 7 years of age (Melby-Larvåg et al., 2012). This study showed that there was no support for conventional claims that NWR has a causal influence on vocabulary development. Related research suggested that children with specific language impairment (SLI) had relatively poor NWR abilities because they were unable to use their existing lexical knowledge to facilitate NWR performance (Melby-Lervåg & Lervåg, 2012). That is, whereas typically developing (TD) children were able to use lexical knowledge (i.e., words or word parts) to reconstruct a nonword for reproduction (a process known as redintegration), children with reduced language ability (those with a language delay, or those with SLI), were unable to recruit the phonological segments or syllables of known words to enhance their success on NWR tasks (Gathercole, 1999; Stokes, Wong, Fletcher, & Leonard, 2006).

If facility with NWR reflects rapid, active, phonological encoding and poor performance is related to the inability to recruit phonological strings effectively, then other language behaviors also would be affected. For instance, to utilize known vocabulary in fluent conversational speech, rapid access of the phonological forms of target lexemes is required. A speaker with poor NWR ability would also evidence reduced use of vocabulary, regardless of vocabulary knowledge, not because VSTM or the phonological loop supports word learning or word use but because both tasks require rapid retrieval of stored phonological knowledge.

VOCABULARY USE

To examine the argument that individuals with poor NWR would also have poor vocabulary use, measures of vocabulary use need to be considered. One measure of the use of lexical knowledge is lexical diversity. Lexical diversity refers to the use of one’s vocabulary knowledge in speech, as measured by counting the number of different words spoken in spontaneous language samples (e.g., Duran, Malvern, Richards, & Chipere, 2004). The speaker with the least diverse language sample will use the same few words repeatedly, whereas the speaker with the most diverse language sample will use many different words, some appearing only once (Duran et al., 2004). Lexical diversity is not simply another measure of vocabulary size. That is, having a word in an expressive lexicon differs from using it in connected speech. Speakers can label many items in a vocabulary test with words that they do not use in conversation. Words used in conversation tend to be of high frequency and/or high phonological neighborhood density, which is assumed to be the result of spreading neural activation during phonological encoding for production (e.g., Dell, 1986).

Various methods of examining lexical diversity have been used (e.g., Duran et al., 2004, Watkins, Kelly, Harbers, & Hollis, 1995). Possibly, the first index of lexical diversity was that proposed by Johnson (1944), who named the ratio of different words (types) to total words (tokens) the type-token ratio (TTR; number of word types divided by the total number of word tokens in a language sample). He introduced it as an experimental metric to be investigated as a measure of vocabulary flexibility or variability. The TTR has been utilized as a measure of lexical diversity to determine developmental trends in vocabulary development and as a tool to compare the language abilities of children with SLI and their TD peers (Watkins, Rice, & Moltz, 1993). However, the TTR has been supplanted by
alternative measures because it is highly influenced by sample length. As a conversation continues, the same words tend to be used repeatedly, reducing the TTR.

One alternative measure is the number of different words that a child could generate in a language sample of spontaneous speech (NDW; Miller, 1991), with some control over the time frame or sample size (Klee, 1992; Watkins et al., 1995). Although a newer method has been proposed, "D" (see Duran et al., 2004), the current study adopts the metric of NDW per 100 tokens (NDW100), for two reasons. First, NDW100 can be calculated electronically as part of the Systematic Analysis of Language Transcripts (SALT) procedures for language sample analysis (SALT Version 2012; Miller & Iglesias, 2012), the software used in the current research. Second, NDW controlled for the total number of words has been used in other developmental studies (e.g., Heilmann, Miller, Nockerts, & Dunaway, 2010).

Lexical diversity has been found to be a useful measure of language production in children who are TD as well as those with language impairment. Duran et al. (2004) reported lexical diversity scores (using D; Malvern & Richards, 1997), collected longitudinally for 32 British children from 18 to 42 months of age, demonstrating continuous increases in lexical diversity across age. With regard to language impairment, children with SLI have been found to use significantly fewer different words in a length-controlled conversational sample than their TD peers (e.g., Klee, Stokes, Wong, Fletcher, & Gavin, 2004), even when lexical knowledge does not differ between the groups (e.g., Stokes & Fletcher, 2000).

**NWR AND LEXICAL DIVERSITY IN CHILDREN**

Evidence of a relationship between NWR and vocabulary knowledge in children in the preschool years is plentiful, but there is less evidence of a relationship between NWR and lexical use in conversational samples. Adams and Gathercole (1995) performed three studies of the relationship. In the first (Adams & Gathercole, 1995), they assigned thirty-eight 3-year-old children with TD language to one of two groups on the basis of good or poor phonological memory skills. The authors showed that the two groups differed significantly in lexical diversity and in the sophistication and the breadth of the grammatical forms they produced in spontaneous speech. These authors reported a significant correlation between total NWR scores and NDW (not controlled for sample length) of $r(29) = .329$. However, vocabulary knowledge as a variable was not controlled in a partial correlation. This first of three studies reported a weak relationship between NWR and vocabulary use in children of average receptive vocabulary scores.

A follow-up study of eighty-seven 4- and 5-year-old TD children did control for vocabulary knowledge (Adams & Gathercole, 1996), using The Short Form of the British Picture Vocabulary Scale (Dunn, Dunn, Whetton, & Pintile, 1982), and the Oral Vocabulary subscale of the McCarthy Scales of Children’s Abilities (McCarthy, 1972), combined for a composite score of vocabulary knowledge. The Information Score of the Bus Story (Renfrew, 1969) was taken as a measure of expressive language. This score is a count of the number of information units (e.g., key words or phrases) that the child includes in the story retell. There was a significant correlation between NWR and vocabulary knowledge, $r(87) = .35$, and between NWR and information scores, $r(87) = .40$. In a hierarchical regression to predict the information score, even though the impact of NWR was low, accounting for only 3.5% of the variance, once vocabulary knowledge had been accounted for, the relationship between NWR and language use was nonetheless significant and was independent of vocabulary knowledge. This second study in the series also reported a weak relationship between NWR ability and vocabulary use in TD preschool children.

In the third study, Adams and Gathercole (2000) examined the relationship between
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NWR and language use (NDW, not controlled for sample length) in a sample of 97 TD children 54–60 months of age. On initial testing, two groups of children were identified on the basis of good and poor NWR abilities ($N = 15$ in each group). The researchers did not control for word knowledge. The authors reported a significant correlation between NDW and NWR, $r(28) = .48$, indicating that NDW accounted for 23% of the variance in NWR scores. However, correlations for the two groups, defined as high and low NWR ability, were not examined separately. Also, as word use must be dependent on word knowledge to some degree (Gupta & Tisdale, 2009), then word knowledge must be controlled if the relationship between NWR and language use is to be explored. In this third study, there was a moderate relationship between NWR ability and vocabulary use, but these important controls were not used.

The message from these three studies is that NWR and vocabulary use may be marginally related in children once vocabulary knowledge has been accounted for. This suggests some relationship between the ability to generate known words rapidly (as occurs in conversation) and the ability to generate novel motor programs rapidly for just-heard nonsense words. We would expect then to replicate this finding in subsequent studies. However, the relationships among NWR, NDW, and vocabulary knowledge is not so apparent in children with SLI. There is evidence that children with SLI perform poorly on NWR. Recent research indicates that late talkers (LTs) also perform poorly on NWR task (Stokes & Klee, 2009a). However, little is known about the relationship between NWR and lexical diversity in very young children who are at the earliest stages of vocabulary development.

This is the focus of the current study. One hypothesis is that children who are slow to develop an expressive lexicon, that is, LTs, would score poorly on NWR tasks and would have low rates of lexical use. In the current study, the 2-year-old participants were divided into two groups, TD children and those with late language emergence (LTs), to explore the relationships among NWR, lexical diversity, and lexical knowledge in the two groups. Stokes (2013) suggested that the crucial point of difference between TD children and LTs at 2 years of age may be that LTs either cannot establish phonological representations that are robust enough for access for word production or that they cannot rapidly retrieve those forms in conversation. Given that NWR requires recruitment and rapid encoding of phonological representations abstracted away from stored language knowledge, then LTs should be significantly worse than TD children on an NWR task, and there should be a significant relationship between NWR and lexical diversity for LTs. It is important that vocabulary knowledge be accounted for in this analysis, as developmental research has shown a moderate relationship between use and knowledge (Adams & Gathercole, 1996).

THE NEUROLOGICAL FRAMEWORK

A logical question at this point is why lexical diversity and NWR would depend on similar processing skills. One hypothesis is that there is an overlapping neural substrate for some components of the two tasks. Although linguistic processing recruits many cortical areas and pathways, there is evidence from both neurophysiological and computational studies to support a dual-pathway (dorsal and ventral) model of the neural substrate of language processing (Hickok & Poeppel, 2007; Rijntjes, Weiller, Bormann, & Musso, 2012; Ueno, Saito, Rogers, & Lambon Ralph, 2011). According to this theoretical account, the dorsal stream (Figure 1), involving the perisylvian region, including the parietal-temporal boundary, the premotor cortex, Broca’s region, the anterior insula, and the posterior inferior frontal gyrus, is primarily responsible for sensorimotor interaction of the kind that underpins NWR and the learning of new vocabulary, via the mapping of auditory input to the articulatory networks.

The ventral stream, involving the posterior and anterior middle temporal gyrus,

posterior and anterior inferior temporal sulcus, and the premotor cortex, according to this theoretical model, is primarily responsible for semantic-phonological/articulatory mapping. This stream provides the neural substrate for word repetition, word generation in naming tasks and spontaneous speech, and word comprehension. Hickok and Poeppel (2007) explained that the model is based on the assumption that there is an interface between auditory-to-motor/articulatory mapping and semantic/lexical-to-motor mapping, which Müller and Palmer (2008) interpreted as the interface of a word’s phonological and conceptual representations, involving the middle and inferior temporal gyri. In this model, the articulatory network of the dorsal stream is recruited for NWR via the dorsal route and for word repetition and word production via the ventral route.

Evidence in support of Hickok and Poeppel’s (2007) proposal came from Ueno et al. (2011) in their neurocomputational model of processing by the dorsal and ventral streams. Ueno et al. (2011) demonstrated the importance of the dorsal route for NWR by stripping out the dorsal route in a simulation, which created a processing system that could perform word repetition but not NWR. This indicated the critical value of the dorsal route for NWR. Word repetition was successfully achieved via the
ventral route. Ueno et al. (2011) described the functioning of the two pathways as a “partial division of labour” (p. 389) between repetition and comprehension/speaking/naming.

In mature or intact neurological systems, processing during NWR flows from the peri-Sylvian region to the motor cortex, engaging the phonological network in the retrieval of stored phonological representations, recruiting activity within the middle-posterior superior temporal sulcus and the dorsal superior temporal gyrus—dissociated from lexemes—to enable NWR. Activity flows then to the articulatory network. During word production, processing flows from the lexical interface via the ventral stream to the motor cortex, described as the articulatory network of the dorsal route. In this way, NWR and word generation may both recruit components of the dorsal route for production but via different starting points. In mature systems, NWR appears to be subsumed by the dorsal route via access of strong phonological representations of segments and biphones. That is, NWR depends on well-established phonological representations, abstracted from stored language knowledge. Nonword repetition then should be related to language knowledge, albeit indirectly. It would be marginally related to lexical diversity in TD children, when vocabulary knowledge is taken into account (Adams & Gathercole, 1996).

In immature neurological systems, immaturity of the areas around the central sulcus (the peri-Sylvian region) would reduce NWR ability by dysfunctional processing from the auditory to the motor cortex. If only the peri-Sylvian (dorsal) and not the ventral route were immature/dysfunctional, then only NWR should be compromised. However, lexical diversity also requires rapid phonological encoding but via the ventral route. If there is a strong relationship between NWR and lexical diversity, then the articulatory network of the dorsal stream would be implicated. If both lexical diversity and vocabulary knowledge (receptive and expressive vocabulary knowledge) were predictors of NWR abilities, then general neuroanatomical immaturity could be assumed.

**SUMMARY AND AIMS**

This study examined the relationship between NWR and language use (lexical diversity) in young children (aged 2 years) while controlling for word knowledge. The participants were divided into two groups, TD children and those with late language emergence (called LTs). Hypothesis 1 is that NWR and vocabulary knowledge may be weakly related in TD children, and there may be a weak relationship between NWR and lexical diversity once vocabulary knowledge has been accounted for. Hypothesis 2 is that in children identified as LTs, both NWR and lexical diversity will be similarly compromised, as both require rapid phonological encoding for production. It is not known whether or not vocabulary knowledge would also be a significant predictor of NWR skills.

The research questions were as follows:
1. What proportion of variance in NWR is accounted for by age, lexical diversity, and lexical knowledge in TD children?
2. What proportion of variance in NWR is accounted for by age, lexical diversity, and lexical knowledge in children described as LTs?

**METHODS**

Participants were 113 monolingual, British English-speaking children 25–29 months of age \( \bar{X} = 27.04, SD = 1.30 \), of whom 61 were female, with no diagnosed developmental disability, as determined from the demographics questionnaire (see later). Children were recruited from local nurseries and parent-toddler groups or a university research database.

**Procedures**

**Parent-report questionnaires**

Parents were mailed an information sheet explaining the study, an informed consent
form, and two questionnaires, which they were asked to complete in no particular order. One questionnaire addressed family/child demographics, including the child’s birth date, age, sex, birth order, medical history, including ear infections, family history of speech/language delay, parents’ education level, concern about language development, and languages spoken in the home; the other focused on the child’s expressive language development, using a form of the MacArthur-Bates Communicative Development Inventory: Word and Sentences (MCDI; Fenson et al., 1993) adapted to British English (Klee & Harrison, 2001). This parent-report measure consists of a vocabulary checklist of 672 words as well as a checklist of grammatical constructions that are likely to be used by children between 16 and 30 months of age. Parents check off the words and constructions they have heard their child say.

This measure was used to identify the two subgroups of children: TD and LTs. The LT status was determined by applying a quantitative cutoff point on expressive vocabulary size. There is no agreed-upon cutoff point, with studies using the 10th (Dale et al., 1998), 16th (Bishop et al., 2012), or 20th (Jones & Smith, 2005) percentiles for age on the MCDI. As there is no consensus for the cutoff point, the mid-level 16th percentile on the MCDI was used here, with children below this cutoff point coded as LTs. Separate z scores were generated for each age group for the MCDI. This resulted in 21 LTs (mean MCDI = 220, SD = 111.73) and 92 TD children (mean MCDI = 482.18, SD = 108.04) meeting criteria for this study.

**Vocabulary knowledge**

The MCDI was normally distributed for both groups (KS = .50, p = .96; KS = .64, p = .81, respectively). The Receptive One-Word Picture Vocabulary Test (Brownell, 2000) was administered to gain an estimation of the size of children’s receptive lexicon. This variable also was normally distributed for LTs and TD children (KS = .73, p = .65; KS = .87, p = .44, respectively).

**NWR task**

The Test of Early Nonword Repetition was designed to assess the NWR ability of very young children by using combinations of CV (C = consonant; V = vowel) and CVC structures that contained consonants that were within the phonetic inventories of 2-year-olds (Stokes & Klee, 2009b). This test contained 15 one-, two-, three-, and four-syllable nonsense words that were presented in live voice. The child rolled a ball down a chute as a reward for attempting to imitate the nonsense word. Responses were scored online. Each correct phoneme was awarded a point, and the total percentage correct was calculated. This variable was normally distributed for LTs and TD children (KS = 1.12, p = .16; KS = .70, p = .71, respectively).

**Lexical diversity**

Play sessions between the parents/caregivers and children of 20-min duration were video recorded. The children were provided with a standard set of toys, including a farmhouse, a dolls house, a train set, and a tea set, and parents were instructed to play with their children in their usual way. Language samples were transcribed using the SALT software (Miller & Iglesias, 2012), and the instructions in the manual were followed for utterance segmentation and markup. Transcription was repeated independently of the first transcription to ensure that transcriptions were accurate. The purpose was not to conduct intertranscriber reliability; rather, every discrepancy was noted, discussed, and an agreement reached so that all data were included for analysis. Lexical diversity was defined as the number of different words spoken by the child in NDW100 to control for sample length. This variable was normally distributed for LTs and TD children (KS = 1.07, p = .20; KS = .78, p = .58, respectively).

**RESULTS**

The descriptive statistics for LTs and TD children are given in Table 1. The groups were significantly different on all variables.
Table 1. Means (standard deviations) of lexical diversity (number of different words), age, receptive vocabulary, NWR, and MCDI expressive vocabulary for typically developing children ($n = 92$) and late talkers ($n = 21$)

<table>
<thead>
<tr>
<th></th>
<th>NDW$_{100}$</th>
<th>Age</th>
<th>ROWPVT</th>
<th>NWR</th>
<th>MCDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typically developing children</td>
<td>49.46$^a$ (6.86)</td>
<td>27.00 (1.32)</td>
<td>31.43$^a$ (7.44)</td>
<td>83.56$^a$ (10.60)</td>
<td>482.18$^a$ (108.04)</td>
</tr>
<tr>
<td>Late talkers</td>
<td>39.52 (10.80)</td>
<td>27.19 (1.30)</td>
<td>21.95 (5.29)</td>
<td>65.80 (17.85)</td>
<td>220.10 (111.73)</td>
</tr>
</tbody>
</table>

Note. MCDI = MacArthur-Bates Communicative Development Inventory; NDW$_{100}$ = the number of different words spoken per 100 tokens; NWR = nonword repetition; ROWPVT = Receptive One-Word Picture Vocabulary Test.

*Groups significant different, $F(1,111) = 28.31$, partial $\eta^2 = .25$; $F(1,111) = 30.56$, partial $\eta^2 = .22$; $F(1,111) = 36.09$, partial $\eta^2 = .25$; $F(1,111) = 99.37$, partial $\eta^2 = .47$; all at $p < .001$, for lexical diversity, receptive vocabulary, NWR, and MCDI, respectively.

A primary question of the study was how much variance in NWR could be accounted for by both vocabulary knowledge and vocabulary use. The question was not how much variance in NWR could be accounted for by group membership. Furthermore, the two groups of children were identified on the basis of MCDI scores. Therefore, multiple regressions were run for each group separately. If group had been entered into the regression as a predictor along with the other variables, then any effect of group would have been eliminated by MCDI scores.

The bivariate correlations among the variables for TD and LT children are given in Tables 2 and 3, respectively. For the group of TD children, NWR was weakly and significantly correlated with age, receptive vocabulary, and expressive vocabulary, but, importantly, it was not significantly correlated with lexical diversity. Table 2 also highlights the significant intercorrelations between age, NWR, and the vocabulary measures. Of note is the weak significant correlation between lexical diversity (NDW$_{100}$) and expressive vocabulary size (MCDI), indicating a shared variance of only 9%. This last point indicates that knowing many words does not equate to higher lexical diversity in conversation among 2-year-olds.

Table 2. Intercorrelations among lexical diversity (number of different words), age, receptive vocabulary, NWR, and MCDI expressive vocabulary for typically developing children ($n = 92$)

<table>
<thead>
<tr>
<th>NDW$_{100}$</th>
<th>Age</th>
<th>ROWPVT</th>
<th>NWR</th>
<th>MCDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (months)</td>
<td>.12</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>ROWPVT</td>
<td>.09</td>
<td>.16</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>NWR</td>
<td>.09</td>
<td>.37$^a$</td>
<td>.35$^b$</td>
<td>-</td>
</tr>
<tr>
<td>MCDI</td>
<td>.30$^a$</td>
<td>.43$^b$</td>
<td>.29$^a$</td>
<td>.46$^d$</td>
</tr>
</tbody>
</table>

Note. Lexical diversity (NDW$_{100}$) = the number of different words spoken per 100 tokens; MCDI = MacArthur-Bates Communicative Development Inventory; MLU = mean length of utterance (words); NWR = nonword repetition; ROWPVT = Receptive One-Word Picture Vocabulary Test (Brownell, 2000).

*aCorrelation is significant at the .01 level (two-tailed).
Table 3. Intercorrelations among lexical diversity (number of different words), age, receptive vocabulary, NWR, and MCDI expressive vocabulary for late talkers (n = 21)

<table>
<thead>
<tr>
<th></th>
<th>NDW100</th>
<th>Age</th>
<th>ROWPVT</th>
<th>NWR</th>
<th>MCDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (months)</td>
<td>.52a</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROWPVT</td>
<td>.43</td>
<td>.20</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NWR</td>
<td>.73b</td>
<td>.42</td>
<td>.26</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>MCDI</td>
<td>.65b</td>
<td>.71b</td>
<td>.34</td>
<td>.66b</td>
<td></td>
</tr>
</tbody>
</table>

Note. Lexical diversity (NDW100) = the number of different words spoken per 100 tokens; MCDI = MacArthur-Bates Communicative Development Inventory; MLU = mean length of utterance (words); NWR = nonword repetition, see text for details; ROWPVT = Receptive One-Word Picture Vocabulary Test (Brownell, 2000).

aCorrelation is significant at the .05 level (two-tailed).
bCorrelation is significant at the .01 level (two-tailed).

were used to tease apart the relationships among the variables.

For the TD children, age, receptive vocabulary, and expressive vocabulary were weakly but significantly correlated with NWR (Table 2). In a multiple regression to predict NWR from age, receptive vocabulary, expressive vocabulary, and NDW100, the predictors together accounted for 29.6% of the variance in NWR scores, $F(4,87) = 9.12, p < .001$, with receptive and expressive vocabulary being the significant predictors, $t = 2.47, p = .02, t = 2.99, p = .004$, respectively. Receptive and expressive vocabulary scores were entered as ordered variables into a hierarchical regression with NWR as the outcome variables. The values of $\beta$ in Table 4 indicate that regardless of order of entry, expressive vocabulary accounted for 14.90% of the variance in NWR scores and receptive vocabulary accounted for 5.8% of the variance, and both were significant variables in the model.

For the LTs, NDW100 and expressive vocabulary were moderately to strongly and significantly related to NWR in a correlation analysis but receptive vocabulary was not. In a multiple regression to predict NWR from age, receptive vocabulary, expressive vocabulary scores, and NDW100, the variables accounted for 60.7% of the variance in NWR, $F(4,16) = 6.17, p = .003$. Only NDW100 was a significant predictor, $t = 2.66, p = .02$, accounting for 52.9% of the variance in NWR, $F(1,19) = 21.30, p < .001$ (Table 5).

**DISCUSSION**

This study examined the relationship between NWR, lexical diversity, and language knowledge in TD children and LTs. In the TD children, who had well-developed expressive lexicons relative to the LTs, the ability to repeat nonsense words was weakly correlated with receptive and expressive vocabulary scores. Together, these variables accounted for 29.6% of the variance in NWR scores. There was no significant relationship between NWR and lexical diversity (NDW100), defining the ability to use known words during conversation.

These results suggest that in this group of 2-year-old TD children, the ability to repeat nonsense words may be a skill relatively independent of other types of linguistic processing, possibly with rapid processing of auditory input to generate novel phonological strings via the dorsal route (Koenigs et al., 2011), as occurs in adults. This skill may reflect the relative maturity of the dorsal tract (Friederici, 2012) in comparison with that of LTs and a decoupling of auditory repetition from stored lexemes but recruitment of phonological representations. This would mean that auditory input in the form of nonwords might be rapidly processed along a pathway from the parietal-temporal boundary and the dorsal superior temporal gyrus (the sensorimotor interface and the region of spectrotemporal analysis) to the articulatory network of the premotor/supplementary motor cortex for reproduction (Hickock & Poeppel, 2007). This account would explain why NWR abilities dissociate from language scores in older children and adults. Phonological representations for biphones (CV or VC) may be so well established that repetition of such strings is highly automatic, bypassing developmentally earlier reliance on support
Table 4. Coefficients for receptive vocabulary and MCDI expressive vocabulary as predictors of nonword repetition for typically developing children (n = 92)

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>SE</td>
</tr>
<tr>
<td>Regression 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>61.99</td>
<td>4.55</td>
</tr>
<tr>
<td>(Constant)</td>
<td>.05</td>
<td>.01</td>
</tr>
<tr>
<td>MCDI</td>
<td>54.50</td>
<td>5.32</td>
</tr>
<tr>
<td>Regression 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>67.75</td>
<td>4.55</td>
</tr>
<tr>
<td>(Constant)</td>
<td>.50</td>
<td>.14</td>
</tr>
<tr>
<td>ROWPVT</td>
<td>.34</td>
<td>.14</td>
</tr>
</tbody>
</table>

Note. MCDI = MacArthur-Bates Communicative Development Inventory; ROWPVT = Receptive One-Word Picture Vocabulary Test (Brownell, 2000).

Table 5. Coefficients for lexical diversity and MCDI vocabulary scores as predictors of nonword repetition for late talkers (N = 21)

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>SE</td>
</tr>
<tr>
<td>1</td>
<td>18.32</td>
<td>10.65</td>
</tr>
<tr>
<td>(Constant)</td>
<td>1.20</td>
<td>2.60</td>
</tr>
<tr>
<td>NDW_{100}</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Lexical diversity (NDW_{100}) = the number of different words spoken per 100 tokens; MCDI = MacArthur-Bates Communicative Development Inventory.

...from stored language knowledge/episodic memory to activate biphone representations. In those children identified as LTs, lexical diversity accounted for NWR scores independently of vocabulary knowledge, as measured by scores on a receptive vocabulary test and a parent checklist of the size of the expressive lexicon. Low lexical diversity scores were related to poor NWR abilities. Reduced proficiency in lexical diversity reflects the inability to rapidly retrieve both a lexeme to express a concept and the phonological representation for that lexeme and an inability to rapidly generate the required motor program and an articulatory/gestural code for word production. Word generation...
occurs via recruitment of the ventral stream, incorporating activation of regions of the temporal and frontal cortex (Hickok & Poeppel, 2007; Koenigs et al., 2011). It is possible that the neural pathway for completion of NWR tasks is immature in LTs such that the dorsal route is not recruited for NWR but the ventral route is activated, overloading functional regions so that both NWR and rapid word generation in conversation are compromised. This account is supported by the discussion by Ueno et al. (2011, p. 392) of how difficult it was for their simulation to process dorsal route tasks via the ventral stream. Alternatively, it is possible that the articulatory network is underdeveloped in LTs, resulting in poorer NWR performance and low rates of lexical diversity. Other developmental research suggests that immaturity of fiber connections of the dorsal stream may contribute to reduced linguistic processing (Friederici, 2012). Studies that map the neuroanatomical substrate against psycholinguistic processing abilities in the same group of children are required to tease apart these explanations.

Related work with similar groups of children suggests that the difficulty for LTs in developing a spoken lexicon is not in storing phonological representations but in activating them for word production. Stokes (2013), in a study of 13 LTs and 50 TD children aged 18 months, found no significant difference in overall vocabulary size, but the LTs had significantly fewer words in their active (spoken) lexicons and more words in their passive (understood but not said) lexicons than the TD children. This result was interpreted to mean that the groups did not differ in their ability to form phonological representations but did differ in their ability to activate those word forms for word production. These converging results from the two studies (Stokes, 2013 and the current research) suggest that the main difficulty for LTs may lie in the articulatory and/or phonological networks of the neural substrate for language processing. This does not mean that LTs have articulation problems (i.e., unclear speech) but rather that they do not have the ability rapidly to access phonologically representations and rapidly to produce motor programs, be they existing programs for known words or new programs for nonsense words.

The study results shed light on the two accounts of NWR introduced earlier. The results for the TD children reflect repetition abilities that are partially dissociated from (i.e., marginally related to) stored vocabulary knowledge per se but that may reflect robust phonological representations for the ambient language biphones. Consequently, these results support the second account that NWR is a test of real-time phonological encoding of stored phonological segments/syllables. The results from LTs also support the second account that NWR is a test of real-time phonological encoding. Both NWR and word production require access to phonological representations for CV/VC combinations. The unique contribution of the current research is the finding that for LTs, the inability to rapidly use a wide range of words in conversation is more strongly related to NWR (in)ability than to a count of the number of words in a child’s spoken lexicon. The implication is that the issue is one of rapid access and use. Here, we have suggested that LTs have immaturity of the shared dorsal neural substrate, which includes the mid-posterior superior temporal sulcus (phonological network), the posterior inferior frontal gyrus, and/or the premotor cortex (the articulatory network), for NWR and rapid word generation.

Implications

The implications from this study are similar to those proposed in studies of the effects of word form on emerging spoken lexicons in TD and LTs (Stokes, 2013). Stokes suggested that LTs had difficulty establishing a spoken lexicon because they were unable to establish sufficiently robust phonological representations to produce words of varying phonological structure. This conclusion was reached because LTs and TD children had similar sized combined lexicons (understood and spoken) but the spoken lexicons of LTs were significantly smaller than those of their same
The therapy implications were that LTs should be systematically taught words of particular phonological structures from carefully selected phonological-lexical networks to lay down strong enough phonological representations to support word production.

The current findings have similar implications. It is possible that a key target of therapy needs to be the establishment of phonological representations from repeated experience of both input and output processing. This is a divergence from current therapeutic practice, which is dominated by approaches that “follow the child’s lead” by providing opportunistic vocabulary items to the child during play and/or daily activities but not requiring imitation or labeling. It is possible that different therapy approaches yield different benefits to individual children (e.g., see Cable & Domsch, 2011, for a review), and therapy incorporating elicited production may be successful for some but not all children. The current findings suggest that research is required to explore the relative effects of intervention methods on growth in children’s expressive lexicons.

The obvious limitation of the research is that it is correlational and draws associations between observed behavioral results and nonobserved neurological underpinnings. However, the approach has been adopted in studies with neurologically impaired adults to further our understanding of this complex area of language processing. This study provides a small beginning to using similar methods to unpack language processing in children.

We have suggested that children identified as LTs may differ from TD children in the development of some areas of the neural substrate hypothesized to underpin NWR and rapid word generation. The findings are tentative and only implicational. The hypotheses arising from this work may be tested in a combination of two approaches. The first is to conduct longitudinal studies of children to define the change in the relationships between repetition and language skills across childhood. The second is to perform concurrent neurophysiological and behavioral studies to confirm or refute the claims made here.

The dorsal/ventral two-route model of language processing is adopted here as a framework in which to begin to conceptualize the neuroanatomical differences that may contribute to performance differences between children developing language typically and those who are not. This does not mean that the authors adopt a modular view of language processing. Rather, we have attempted to map behavioral observations onto purported neuroanatomical pathways of processing, thereby suggesting that there may be specific neurobiological differences in children who are, and who are not, late in producing words. Recent advances in the realms of neuroanatomy and cognitive science have opened the doors to new ways of reconciling information from disparate areas of research. Forming tentative associations, as we have done here, may provide a catalyst for exploring relationships more directly.

REFERENCES


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