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Lexical processing of nouns and verbs at 36 months of age predicts concurrent and later vocabulary and school readiness

Ashley Koenig[1,2], **Sudha Arunachalam**[3], **Kimberly J. Saudino**[1]

[1]Boston University

[2]University of Bath

[3]New York University

Abstract

Children's lexical processing speed at 18 to 25 months of age has been linked to concurrent and later language abilities. In the current study, we extend this finding to children aged 36 months. Children (N = 126) participated in a lexical processing task in which they viewed two static images on noun trials (e.g., an ear of corn and a hat), or two dynamic video clips on verb trials (e.g., a woman stretching and the same woman clapping), and heard an auditory prompt labeling one of them (e.g., "Where is she stretching?"). They also participated in standard assessments of language and school readiness. The results indicated that lexical processing speed (i.e., how long they required to look to the labeled image or scene) was associated with measures of concurrent receptive vocabulary, as well as receptive vocabulary and school readiness two years later, although the associations are weaker than for younger children.

In the first years of life, children simultaneously acquire vocabulary and grammar, and develop incredible skill at rapidly comprehending and producing language. These abilities are interwoven. For example, to learn a new word, children can process the sentence in which it occurs and use the vocabulary and grammatical elements they already know to help them decipher the unfamiliar words (e.g., Gleitman et al., 2005). Unsurprisingly, therefore, researchers have long been interested in examining relations among components of language knowledge and language processing ability.

One powerful relation that has been well studied is between lexical processing speed and concurrent and later vocabulary. Lexical processing speed is typically operationalized as the speed with which participants look to an image of a named referent. In several studies, Fernald and colleagues have demonstrated that lexical processing speed increases with age during the second year of life (e.g., Fernald et al., 1998) and is associated with concurrent vocabulary size (Fernald, Perfors, & Marchman, 2006; see also Peter et al., 2019). Importantly, lexical processing speed is a good predictor of outcomes: faster processing speed at 25 months is related to linguistic and cognitive measures, including IQ, at 8 years of age (Marchman & Fernald, 2008).

Corresponding author: Sudha Arunachalam, sudha@nyu.edu.

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To measure lexical processing speed with children, one of a number of related paradigms is typically used: looking-while-listening (e.g., Fernald, Pinto, Swingley, Weinberg, & McRoberts, 1998; Fernald, Zangl, Portillo, & Marchman, 2008), intermodal preferential looking (e.g., Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987; Hirsh-Pasek & Golinkoff, 1996), and visual world (e.g., Trueswell, Sekerina, Hill, & Logrip, 1999). Although there are some methodological differences among these paradigms, the basic structure involves presenting children with images or videos depicting the referents of familiar words (e.g., a picture of a ball next to a picture of a shoe), paired with an auditory stimulus directing their attention to one (e.g., "Where's the ball?"). Lexical processing speed can be defined as the latency to look to the target image in response to the auditory prompt. This measure is not a direct indicator of whether children know the named words, although it is undoubtedly related. Instead, it reveals how quickly children access the word's lexical representation and shift their gaze toward the image that best depicts its meaning.

In the current study, we add data on lexical processing speed and its associations with other language and cognitive measures in a sample of 126 typically-developing children. Our goal is to evaluate whether lexical processing speed predicts concurrent and future abilities, with two main departures from prior work. First, we studied slightly older children. Fernald et al. (2006) found that mean response latency and receptive vocabulary scores (as measured by the PPVT, Dunn & Dunn, 2007) at 25 months of age were strongly correlated, with $r = -0.60$ (the correlation is negative because lower latencies indicate faster processing). However, some studies suggest that over the next year or so of life, response time becomes less closely related to offline measures (e.g., Mahr & Edwards, 2018; Peter et al., 2019). One possible explanation for the weakened association between these measures in these studies is methodological: Mahr and Edwards (2018) included phonological and semantic competitors to the target word, making the task more difficult than the simple two-image task used by Fernald and colleagues, and Peter et al. (2019) tested words that may have been quite easy (and thus boring) for the older children in their sample. Another possible explanation is that the weakened association reflects true developmental change. In particular, the robust phonological and semantic representations for relatively familiar words that permit faster lexical processing may have reached a threshold by the end of the third year of life. Moreover, children may have developed several strategies for language comprehension and vocabulary learning such that fast lexical access of particular lexical representations is no longer required for broader language gains. Thus, additional evidence is needed on how lexical processing speed in children older than 25 months is related to other measures.

Although other studies have used similar experimental paradigms with children at 36 months and older, their goals have been to examine different populations (e.g., bilingual children; Hurtado, Grüter, Marchman & Fernald, 2014), more complex linguistic skills than simply lexical access (e.g., using a determiner's gender to predict a noun; Lew-Williams & Fernald, 2007), or competition effects with phonological and semantic competitor items in a more complex display (Law, Mahr, Schneeberg, & Edwards, 2017; Mahr & Edwards, 2018). Thus, the results from the current study will reveal whether simple lexical processing speed remains a powerful predictor even for 36-month-olds, and in turn, will have implications for evaluating continuity in the development of language knowledge and language processing skill.

In a second departure from previous work, we included both noun and verb trials in the lexical processing task. While almost all similar studies have only included noun trials, we added verbs because they play a critical role in language development. Verbs determine the number and type of other grammatical elements that can occur in a sentence; therefore, verb knowledge permits children to produce full sentences with adult-like grammar. Indeed, toddlers' production of verbs predicts their later grammar skills better than their production of nouns (Hadley, Rispoli, & Hsu, 2016). Hence, we might hypothesize that lexical processing of verbs would better predict outcomes than lexical processing of nouns. However, a methodological caveat calls this hypothesis into question. While prior work testing noun referents in lexical processing tasks has almost exclusively used static images to depict those referents, most verb referents are best depicted using dynamic action scenes in which participants can view the referent event unfold over time (e.g., Konishi, Stahl, Golinkoff, & Hirsh-Pasek, 2016; Valleau, Konishi, Golinkoff, Hirsh-Pasek, & Arunachalam, 2018). We know less about how eye gaze measures of lexical processing with dynamic scenes are related to outcomes. A handful of studies have used dynamic scenes to depict verb referents in eye-tracking tasks with young children (Bergelson & Swingley, 2013; Goldfield, Gencarella, & Fornari, 2016; Huttenlocher, Smiley, & Charney, 1983; Golinkoff et al., 1987; Horvath, 2019; Horvath & Arunachalam, under review; Naigles, 1997; Naigles & Hoff, 2006; Valleau et al., 2018). Related to the current study, Goldfield et al. (2016) found that eye gaze measures of verb knowledge correlated with PPVT scores in children ages 3 to 5 years (they did not examine lexical processing speed specifically). In contrast, Valleau et al. (2018) found that lexical processing speed for verbs did not correlate with expressive vocabulary for 22- to 23-month-olds—though it did for nouns, just as in prior work (e.g., Fernald et al., 2006). However, in a study of older children with autism spectrum disorder in the same paradigm as Valleau et al. (2018), latency did correlate with vocabulary for both nouns and verbs (Horvath, 2019; Horvath & Arunachalam, under review). Clearly, more evidence is needed. Therefore, in the present study, where we find significant effects of lexical processing speed collapsed across trials, we include secondary analyses that separate noun and verb trials to provide preliminary insight into the methodological question of whether verb trials with dynamic scenes show the same patterns as noun trials with static images.

To examine lexical processing, we used a variant of Fernald et al.'s (1998) lexical processing task. In addition to including verb trials as well as noun trials, one additional difference also shared by Valleau et al. (2018) (and Goldfield et al. 2016, although their paradigm differs from the current paradigm in several other ways) bears mention: while the standard paradigm presents an auditory label while the two test images are on the screen, in our paradigm the images are replaced with a centrally-positioned fixation star as the test prompt is heard and then the images reappear. This design has two advantages. First, because in the looking-while-listening paradigm, children will happen to be looking at the target at the onset of the word on approximately half of the trials, these trials cannot be included when measuring latency. Because in our task, children are looking at the center of the screen at word onset, the latency of their first saccade toward the target scene can be measured on all trials (only two trials out of 1562 were excluded from the current data set because the child was looking at one of the scenes at word onset). Second, because dynamic scenes were used to depict verbs, this design choice ensured that children were able to process the auditory stimuli without being distracted by the movement in the visual scenes.

We examined performance on the lexical processing task in relation to scores on standard assessments of receptive language, expressive language, and school readiness (as measured by a test of concept knowledge in domains such as letters and numbers). Our primary research question was: does lexical processing speed at 36 months predict (1) concurrent language and (2) language and school readiness at 60 months? We predicted that it would, but given that some studies have suggested that for children older than 24 months, lexical processing may be less closely related to language development (Mahr & Edwards, 2018; Peter et al., 2019), we predicted that the strength of these associations would be smaller than in prior work with younger children. As an additional exploratory research question, we asked whether these associations would differ for noun trials and verb trials. Although verb knowledge is expected to support language development more strongly than noun knowledge (e.g., Hadley, Rispoli, & Hsu, 2016), we do not yet have the empirical foundation to know whether the current task overcomes the methodological challenges associated with depicting verbs with dynamic scenes in a lexical processing task (and interpreting the resulting data). The current findings will thus contribute to this empirical foundation.

Methods

The data are part of a study conducted by the Boston University Twin Project from 2012–2017, involving 310 same-sex twin pairs, 274 of which visited at all three time points: within approximately one month of their 3rd, 4th, and 5th birthdays (Saudino & Ganiban, 2019). Children participated in a battery of tasks, and parent report measures were also collected. For the current study, we used data from a subset of the measures, specifically those focusing on language and school readiness, from a subset of the children at their Year 3 and Year 5 visits.

Participants

Although 582 children in the sample participated in the lexical processing task at their Year 3 visit, because of the intensive and time-consuming manual eye-gaze coding procedure, we randomly selected one twin from 126 of the twin pairs (57 were the first-born twin, and 69 were the second-born twin). We chose a target sample size of 112, set an achievable time frame for coding this number (including reliability coding), and coded as many children's data as possible within that time, slightly overshooting our goal. We set the target sample size by estimating a medium effect size of −0.3 for the correlation between lexical processing speed and language outcomes (Fernald et al. 2006 had a large effect size, but recall that we estimated that ours would be smaller) and aimed for 0.90 power to detect an effect with an alpha level of 0.05. Children who were being raised multilingually were not included. Following Cattani et al. (2014) we defined multilingualism as having exposure to English less than 60% of the time, but only two of the included participants had as little as 60% exposure to English; 92% of participants had 80% or more exposure to English.

The final sample of 126 children included 70 females and 56 males (mean age = 36.2 months, *SD* = 0.7 months). Ethnicity was primarily non-Hispanic/Latino (*n* = 122, Hispanic/

Latino = 4), and White (*n* = 116, Asian = 1, Mixed Race = 9). Family socioeconomic status (SES) was computed using the *Hollingshead Four-Factor Index of Social Status* (Hollingshead, 1975), which is a composite score based on maternal and paternal education and occupation status. Mean SES was 52.4 (*SD* = 8.8) indicating that the sample was primarily middle- to upper-middle class, but ranged from low to high SES.

Measures

From the Year 3 visit, we used data from the lexical processing task as well as two standard assessments of language, the NIH Toolbox Picture Vocabulary Test (TPVT; Gershon et al., 2013) of receptive vocabulary, and a parent report measure of productive language from the Language Development Survey (LDS; Rescorla, 1989). From the Year 5 visit, we used data from the TPVT and *Bracken School Readiness Assessment* (*BSRA*; Bracken, 2002). These measures are described in more detail below.

Lexical processing task.—The lexical processing task involved 13 trials. The target words were chosen by Konishi et al. (2016) who used a version of the task with 2.5-year-olds. They chose the words from the MacArthur-Bates Communicative Development Inventory (MCDI; Fenson et al., 1994) and from nouns and verbs known by 3- to 5-year-olds in Masterson, Druks, and Galliene (2008). From Konishi et al.'s trials, we selected 13 that we judged to include later-acquired words, either based on parent report data on children's vocabulary knowledge from Wordbank (Frank, Braginsky, Yurovsky, & Marchman, 2016), or because the words appeared only on Masterson et al.'s list and not the MCDI. The 7 targeted nouns were *airplane*, *corn*, *crab*, *goldfish*, *hamburger*, *rocketship*, and *squirrel*; the 6 targeted verbs were *lift*, *march*, *rip*, *roll*, *shake*, and *stretch*. We surmised that these slightly more difficult words would keep the attention of 36-month-olds better than earlier acquired words (see also Peter et al., 2019).

The visual stimuli were also created by Konishi et al. (2016) and consisted of images of objects and animals (noun trials) and videos of people performing everyday actions (verb trials). The pairing of each target with a distracter was identical to Konishi et al. (2016). The verb trials involved the same actor and object for both actions in the pair, and each trial either involved two intransitive verbs labeling one-participant events (e.g., *stretch* and *clap*) or two transitive verbs labeling two-participant events (e.g., *roll* (ball) and *bounce* (ball)). Appendix A provides a list of all target and distracter images.

Auditory stimuli were recorded by Valleau et al. (2018) in a sound-attenuated booth. To create the task, we synchronized the visual and auditory stimuli as illustrated in Figure 1. Each trial lasted 10 to 12 seconds for a total task duration of two minutes and 35 seconds. The side of the screen on which the target appeared (left or right) was counterbalanced across trials. Each trial comprised a Familiarization phase and a Response phase. During Familiarization, children viewed two images (on Noun trials, e.g., an ear of corn and a hat) or two dynamic videos (on Verb trials, e.g., a woman stretching and the same woman clapping), simultaneously and side-by-side on the screen. They heard attention-getting language, e.g., "Look! Wow!" Then, during Response, the two images or videos disappeared, and a centrally positioned yellow star appeared, during which children heard the test query, e.g., “Where is the corn?” The two images or scenes then reappeared accompanied by a “ding” sound to facilitate coding (see below), and the test query repeated, e.g., “Do you see the corn?” Although some children pointed in response to the pre-recorded query, they were not encouraged to do so and were given no feedback.

Standard assessments.—The TPVT is a computerized receptive vocabulary task that is part of the NIH Toolbox Cognition Battery (Gershon et al., 2013). It is similar in format to the Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 2007): children view four pictures and hear a spoken word naming one of them; their task is to indicate which picture matches the word. It differs from the PPVT in having a fixed length of 25 items and requiring only 5 minutes to complete. TPVT and PPVT scores are highly correlated in the norming sample for ages 3 to 15 years ($r = 0.90$; Gershon et al., 2013). For the present analyses, we used age-adjusted scaled scores, in which each participant is compared to those in the normative sample within the same age band (here, 3-year-olds for the Year 3 visit data and 5-year-olds for the Year 5 visit data); these are standard scores (i.e., with a mean of 100 and standard deviation of 15).

The Language Development Survey (LDS) is a parent report survey about children’s vocabulary and word combinations. Although it is not normed for 36-month-olds and children were generally at ceiling on the vocabulary portion of the assessment, we included the average length of phrase measure as a measure of grammatical complexity. This measure is calculated as the average number of words in caregivers’ report of three of the child’s “longest and best sentences or phrases” (Rescorla & Achenbach, 2002).

The BSRA is a standardized test of concept knowledge in six domains thought to be necessary for success in kindergarten and elementary grades: colors, letters, numbers and counting, sizes, comparisons, and shapes. For each item, the examiner prompts the child to select a picture from an array (e.g., “Look at all of the pictures. Show me which animal is big”). The BSRA yields standard scores based on age (i.e., with a mean of 100 and a standard deviation of 15). We used a composite standard score of all six domains. Inter-rater reliability was evaluated for the Boston University Twin Project’s full sample, of which the present study uses a subset, by Micalizzi, Brick, Flom, Ganiban, and Saudino (2019). They had a second rater complete BSRA ratings for 20% of the sample; the intraclass correlation between raters was high (.99; $p<.01$).

Coding and Analysis

Lexical processing task.—We calculated children’s latency to find the named target on each trial. The video recordings of children’s eye gaze were manually coded by a trained coder in Final Cut Pro at a frame rate of 30 frames per second. For each trial, two timestamps were coded from the audio stream: the onset of the target word and the onset of the ‘ding’ corresponding with the reappearance of the stimuli after the test query. Two gaze measures were coded from the video relative to these: the participant’s first look to the scene on the left side of the screen after the onset of the target word, and the participant’s first look to the scene on the right side of the screen after the onset of the target word. Saccades toward the left or right scene were coded on the frame before a visible shift occurred to partially account for time needed to program and launch a saccade. For each trial, target latency was calculated as the time, in milliseconds, from the onset of the 'ding' to the first look to the target scene (either on the left or right, varying by trial), regardless of whether this was the first saccade (i.e., whether or not the child looked to the distracter before the target). Negative values were recorded for trials ($n = 259$ of 1562) on which children shifted gaze between word onset and the onset of the 'ding.' We included these values because adults (e.g., Altmann, 2004) and children (e.g., Martarelli & Mast, 2011) launch saccades to locations where objects were previously located even if they are not currently visible; pilot testing confirmed that children sometimes did so in this task as well. Trials for which target latency was longer than 1800 ms were excluded prior to analysis (e.g., Fernald et al., 2006). One of two additional trained coders independently coded all trials from 18 participants (14%); agreement between the second coder and the primary coder was 91%, with most disagreements consisting only of one-frame differences (agreement is 98% if one-frame disagreements are discounted). Intra-class correlation was used to assess inter-rater reliability (McGraw & Wong, 1996) with the irr package (Gamer, Lemon, & Singh, 2019) in R version 3.5.1 (R Core Team, 2018). A one-way agreement, single-measures ICC was excellent, 0.98, indicating high agreement across coders. The primary coder's coding was used for the final data set.

Analyses were conducted in R version 3.5.1 (R Core Team, 2018). The goal of the analyses was to examine whether participants' mean target latency[1] predicted their concurrent and later scores on the standard assessments. We used regression models and included demographic factors as fixed effects in addition to target latency. The principal analyses collapsed across all trials, but where overall latency scores were found to be predictive, we also evaluated noun and verb trials separately to provide preliminary information about how word type may matter, acknowledging that these data are noisier because they only include half of the trials. The data file used for analysis is available on OSF (doi:10.17605/OSF.IO/5WVXH).

Results

In the lexical processing task, some children did not complete all 13 trials of the task. We included only those trials that they did complete. We excluded 18 trials from 17 children because the child was blinking or looking away from the screen during the analysis window, or had been, and continued to, look at the target from before word onset. The majority of the children ($n = 79$) contributed data on all 13 trials. The mean number of trials included across the sample was 12.4, with 3 children contributing 8 trials, and 44 contributing between 10 and 12.

Shapiro-Wilk tests revealed that latencies did not significantly differ from the normal distribution for all trials ($W = 0.99$, $p = 0.22$), for noun trials only ($W = 0.99$, $p = 0.46$), or verb trials only ($W = 0.99$, $p = 0.78$). Not surprisingly given that verb trials included dynamic scenes, mean verb latency was longer than mean noun latency (e.g., Valleau et al.,

[1]Thanks to an anonymous reviewer for suggesting that we use median values; we repeated all analyses with the median and found an identical pattern of results.

2018) (but note that because we measured latency from the onset of when the scenes reappeared on the screen after word onset, rather than from word onset, these latencies are not directly comparable to those in other studies). Noun and verb latencies were moderately correlated ($r(124) = 0.43$, $p < .0001$). See Table 1 for descriptive statistics for the lexical processing task and standardized assessment measures.

We first asked whether latency in the lexical processing task predicted concurrent language measures, specifically scores on the TPVT at 36 months and the LDS average length of phrase. We included as fixed effects the demographic factors of socioeconomic status, sex, ethnicity, race, and birth order of the twin. See Tables 2 and 3 for the model parameters. Figure 2 depicts scatterplots for relations between latency and concurrent and future outcome measures.

The results show that latency does predict TPVT both when collapsing across all trials and when looking at noun and verb trials separately, but latency does not predict average length of phrase. We did not, therefore, pursue analyses on noun trials alone for average length of phrase, but given that verb knowledge is expected to predict grammatical knowledge better than noun knowledge (Hadley et al., 2016), we did examine verb trials alone; no significant effect of latency was found.

Next, we assessed relations with later language. We asked whether lexical processing speed predicted TPVT outcome at 60 months, including the same demographic factors. Some children did not do the TPVT at 60 months ($n = 15$). Children who received a score of 0 (bottomed out) ($n = 3$) were excluded from analysis. Overall latency predicted TPVT at 60 months. We therefore followed this analysis with individual analyses for only noun trials and only verb trials, but neither showed that latency was a significant predictor of TPVT at 60 months. See Table 4 for the model parameters.

We then added TPVT at 36 months to the model in Table 4 to see if overall latency predicts TPVT at 60 months *over and above* TPVT at 36 months. See Table 5. The results indicate that overall latency no longer is a significant predictor of TPVT at 60 months. However, TPVT at 36 months also does not predict TPVT at 60 months ($r(106) = 0.18$, $p = 0.053$).

Finally, to ask whether lexical processing at 36 months is related to a measure that is not strictly language specific, we evaluated predictive value for the BSRA. Some children ($n = 17$) did not have BSRA data at 60 months. See Table 6. These regressions reveal that overall latency and latency on noun trials alone do predict BSRA scores at 60 months (but for verb trials alone, latency is not a significant predictor, $p = 0.084$). However, the main effect of lexical processing did not remain when TPVT at 36 months was added as a predictor. That is, lexical processing did not predict later BSRA scores over and above TPVT at 36 months. Interestingly, lexical processing but not TPVT at 60 months predicted BSRA scores, indicating that lexical processing at 36 months is a better measure of later school readiness than is vocabulary size at 60 months. This also held for noun trials only, but not verb trials (see Table 7).

Overall, with respect to lexical processing and concurrent language, the results support prior work, showing that the latency measure on the lexical processing task taps into language ability even at 36 months of age, and even though we included verbs as well as nouns in the task. With respect to predictive ability, lexical processing predicted vocabulary and school readiness scores two years later, but not over and above vocabulary at 36 months.

Discussion

Individual differences in early language ability, including language processing, are important predictors of concurrent and future language and cognitive performance. Lexical processing speed in particular has been shown to predict concurrent and later vocabulary knowledge in children ages 18 to 25 months. Lexical processing speed may both be a consequence and a cause of better vocabulary knowledge—it may reflect robust representations that are easy to access, and it may allow children to learn new vocabulary by quickly accessing those words in a sentence that they already know (e.g., Fernald et al., 2008). Although the underlying cause of these associations is not fully understood, it is by now apparent that measuring lexical processing can serve as a valuable tool for researchers, and possibly clinicians, seeking to understand children's language abilities.

Eye gaze as a measure of lexical processing speed has been well established in the literature for many years. In a simple task, children view two images or scenes side-by-side, hear a sentence or query labeling one of them, and how quickly they look to the correct image or scene is taken as an indicator of lexical processing speed. In the current study, we expanded prior work using this kind of task, which has shown associations between processing and both concurrent and future language and cognitive measures, with 126 children (most similar studies of lexical processing speed include only 30 to 60 children). We tested slightly older children—at their third birthdays—to see if this measure is still predictive of concurrent and future abilities even given substantial developmental changes in processing, gaze patterns, and language knowledge. In addition, we included verb trials as well as noun trials. Given the importance of verbs for language development, it is critical to understand individual differences in verb vocabulary.

The results partially supported those of prior work. Lexical processing speed was associated with current receptive vocabulary (as measured by the TPVT) and current length of phrase produced (as reported by parents on the LDS). It was also associated with outcomes: receptive vocabulary (also measured by the TPVT) and school readiness at 60 months (as measured by the BSRA). The current results document that even with slightly older children, previously observed associations between lexical processing speed and concurrent vocabulary hold, although these associations are weaker than with younger children, as we discuss below. We further found weak associations with later vocabulary and school readiness measures.

Unlike Marchman et al. (2018), who examined lexical processing in 18-month-olds born pre-term, we did not find that lexical processing was predictive of outcomes when concurrent vocabulary was also included in the model. We suggest that this is because by 36 months of age, lexical processing abilities have largely played their role in helping children to learn new word meanings and no longer have as strong a predictive ability. Further, the magnitude of the correlations we found between concurrent language measures was smaller than in prior work. Fernald et al. (2006) report that 25-month-olds showed a correlation of −0.60 between latency in their lexical processing task and receptive vocabulary scores on the PPVT, while we found a correlation of only −0.27. Although this difference could be related to methodological differences between their paradigm and ours, we suspect it is related to the older age of the children we studied. Peter et al. (2019) also found much smaller correlations with concurrent vocabulary size for older children (age 31 months) than younger children (age 19 months). Although they suspected this might be due to the selection of vocabulary words (which were quite easy for the 31-month-olds and may not have held their attention), the concordant results from the current study suggest that this may be a true difference between younger and older children. Goldfield et al. (2016) used dependent measures other than latency (looking time to target, and duration of longest look) to correlate with 3- to 6-year-olds' PPVT scores; nevertheless, the correlations of eye gaze measures with PPVT were of a similar size to ours once they had controlled for age in a series of partial correlations. Further, Mahr and Edwards (2018) found that relations between lexical processing speed and vocabulary size are smaller with older children, although they used a much more complex paradigm with three distractors including phonological and semantic competitors, which may rely on other abilities. Taking these studies together with the current results, the evidence seems strong that that lexical processing at 36 months, while still related to vocabulary size, is more weakly related than it is a year or two earlier.

This may indicate that the learning mechanisms children use to acquire new vocabulary change over the preschool years. For younger toddlers, fast lexical access of familiar words can help them to assign meaning to new words in the same sentence (e.g., Fernald et al., 2008; see He & Arunachalam, 2018 for a recent review). But for older children, fast lexical access may have somewhat outlived its usefulness in helping children acquire new words (e.g., Mahr & Edwards, 2018). It could be that for older children, other mechanisms become more important, such as rapidly building a syntactic structure for the sentence in which the word occurs (e.g., Trueswell & Gleitman, 2007). The notion that different mechanisms for word learning are important at different points in development is not new; it is well described for the first and second years of life (e.g., Hollich, Hirsh-Pasek, & Golinkoff, 2000). However, this line of inquiry should be continued throughout the preschool years to determine which word learning mechanisms are most important at 36 months and beyond. Thus, we see the results of the current study as part of a larger story of how the relation between lexical processing and other language measures changes over development, and what this might tell us about the relative importance of different kinds of learning mechanisms throughout.

With respect to verbs vs. nouns, the results suggest that verbs show fewer associations with other measures than nouns, although the small number of each trial type makes this conclusion tentative. For example, it is interesting that verb latency did not predict average length of phrase on the LDS, given that greater verb knowledge is expected to help children achieve greater gains in grammar (e.g., Hadley et al., 2016). At this point, we lack sufficient evidence to say whether this difference is, for example, about the children's slightly older age (Hadley et al. studied 2-year-olds) or about the appropriateness of the latency measure given dynamic scenes—previous work has been mixed on this issue (e.g., Valleau et al., 2018). The fact that our results for verb latency were overall similar to those for noun latency may suggest that the measure is appropriate, but that the relationship to other measures is simply not strong enough to manifest in comparisons to standard assessments. Although more work needs to be done to help tease apart these different possibilities, we think it is worth developing eye gaze assessments for verb knowledge that do yield robust, reliable, and valid results. A focus on verbs—understanding what verbs children know, how robust those representations are, and what factors lead to their acquisition—will be critical if we are to arrive at a full picture of lexical acquisition (e.g., Horvath & Arunachalam, 2019).

Overall, the findings of the current study have both theoretical and practical implications. Theoretically, we support prior work showing that speed of lexical processing predicts language and cognitive outcomes, pointing to continuity in development. However, these associations are weaker, and do not predict outcomes over and above concurrent receptive vocabulary size, suggesting that mechanisms and abilities other than fast lexical processing are also coming into play that influence the process of vocabulary acquisition.

Some limitations of this work are important to mention. One limitation concerns the nature of the sample, which consisted of one child from each of 126 twin pairs. We took this approach because the focus of our question was on the predictive association between lexical processing and later vocabulary and school readiness and not on genetic contributions. Selecting one twin per family allowed for independent data points in our data set. However, it may be that children who are members of a twin pair differ systematically from singleton children. As a group, twins tend to be slightly delayed in their language and cognitive ability as compared to singletons (e.g., Mittler, 1970; Rutter & Redshaw, 1991); but, the age-adjusted standard scores on the TPVT at 36 months have a mean value of 98, very close to the standard score mean of 100, suggesting that the sample in the current study was not delayed. A second limitation is the relatively small number of trials included. We chose a subset of the trials used by Konishi et al. (2016) and Valleau et al. (2018) in order to keep the task short and to remove the earlier-acquired words that may have bored children (Peter et al., 2019), but future work should use a larger number of trials; in particular, this might allow for more robust comparisons of noun trials and verb trials. Despite these potential limitations, the current study makes unique contributions to the literature.

Several important questions remain. Although we argue, like other researchers, that the latency measure is reflective of lexical processing, we still know little about what underlying processes are involved in accessing a lexical representation in such a task. As in prior work, we selected target words that we expected children to know; that is, the task was not necessarily meant to reveal whether children knew the meanings of the words. Lexical processing speed could still, however, indicate something about the depth or quality of the lexical representation (e.g., Borovsky, Ellis, Evans, & Elman, 2016; Chita-Tegmark et al., 2015), even at 36 months of age.

Second, although we have demonstrated that certain abilities are correlated with each other, our goal was not to examine underlying causal relationships or domain-specific associations. Some prior studies have addressed these issues, examining, for example, associations between parental language input and language processing (e.g., Hurtado, Marchman, & Fernald, 2008; Mahr & Edwards, 2018; Weisleder & Fernald, 2013). Fernald and colleagues have demonstrated that for children under 25 months of age, lexical processing speed mediates the relation between the quantity of language input children are exposed to and their vocabulary size (Hurtado, Marchman, & Fernald, 2008; Weisleder & Fernald, 2013). The more language children hear, the more they exercise their lexical access abilities, and in turn, the better their language outcomes. However, Mahr and Edwards (2018) found no such mediating association for slightly older children (28 to 39 months). Thus, as we have suggested, it may be that for older children, the mechanisms by which children acquire vocabulary may be somewhat different than they are for younger children. Additional research that spans the preschool years will help to evaluate continuity in the roles that language input plays in language processing speed and other language outcomes.

Practically, this work may support the development of eye-tracking assessments for lexical knowledge and processing. Assessing receptive language is a critical challenge for both researchers and clinicians. Young children are not always cooperative in tasks requiring them to point to labeled items, and thus estimates of language ability may be unduly influenced by behavior. For children at or older than 36 months, measures involving touchscreens may be useful (e.g., Friend, Schmitt, & Simpson, 2012; Golinkoff et al., 2017). However, children with developmental disorders pose extra challenges even at older ages. For children with impairments affecting the motor system, such as cerebral palsy, performance on standard assessments may reflect motor ability rather than language skill (e.g., Geytenbeek, Heim, Vermeulen, & Oostrom, 2010). Similarly, children with autism spectrum disorder may perform poorly on assessments due to high demands for cooperation and social interaction (e.g., Brady, Anderson, Hahn, Obermeier, & Kapa, 2014; Brady, Thiemann-Bourque, Fleming, & Matthews, 2013). Eye-tracking has been lauded as a potentially useful tool for these populations because of its low task demands and the fact that eye movements can reflect implicit, rather than only explicit, knowledge (e.g., Brady et al., 2014; Cauley, Golinkoff, Hirsh-Pasek, & Gordon, 1989; Chita-Tegmark, Arunachalam, Nelson & Tager-Flusberg, 2015; Geytenbeek et al., 2010; Horvath & Arunachalam, submitted; Swensen, Kelley, Fein, & Naigles, 2007; Venker & Kover, 2015). Although the current study used manual coding of eye gaze, an eye-tracker would yield the same kind of data but much more quickly analyzed.

Measuring lexical processing, over and above static vocabulary knowledge, has become recognized as an important avenue for research in this area (e.g., Pace, Luo, Hirsh-Pasek, & Golinkoff, 2017). We are just at the beginning stages of establishing a knowledge base to support the development of an eye-tracking language assessment tool. The current findings add to this base; for example, although we found that lexical processing did not predict receptive vocabulary on the TPVT at 60 months over and above TPVT at 36 months, a lexical processing task involving eye-tracking might still be beneficial for predicting outcomes in children for whom the TPVT is not valid. We suggest that it is worth exploring eye-tracking assessments of language processing in future work, both for typically developing children and for clinical populations.

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Appendix A.: List of visual stimuli.

Type	Target	Distracter
Noun	Airplane	Orange
	Corn	Hat
	Crab	Pancakes
	Goldfish	Doughnut
	Hamburger	Tiger
	Rocketship	Giraffe
	Squirrel	Grapes
Verbs	Lift	Pull
	March	Spin
	Rip	Read
	Roll	Bounce
	Shake	Open
	Stretch	Clap

References

Achenbach TM (1991). Manual for the Child Behavior Checklist/4–18 and 1991 profile. University of Vermont, Department of Psychiatry.

Altmann GT (2004). Language-mediated eye movements in the absence of a visual world: The 'blank screen paradigm'. Cognition, 93(2), B79–B87. [PubMed: 15147941]

Bergelson E, & Swingley D (2013). The acquisition of abstract words by young infants. Cognition, 127(3), 391–397. [PubMed: 23542412]

Borovsky A, Burns E, Elman JL, & Evans JL (2013). Lexical activation during sentence comprehension in adolescents with history of Specific Language Impairment. Journal of communication disorders, 46(5–6), 413–427. [PubMed: 24099807]

Borovsky A, Ellis EM, Evans JL, & Elman JL (2016). Semantic structure in vocabulary knowledge interacts with lexical and sentence processing in infancy. Child development, 87(6), 1893–1908. [PubMed: 27302575]

Bracken BA (2002). Bracken School Readiness Assessment. San Antonio, TX: The Psychological Corporation.

Brady NC, Thiemann-Bourque K, Fleming K, & Matthews K (2013). Predicting language outcomes for children learning Augmentative and Alternative Communication: Child and environmental factors. Journal of speech, language, and hearing research, 5(56), 1595–1612.

Brady NC, Anderson CJ, Hahn LJ, Obermeier SM, & Kapa LL (2014). Eye tracking as a measure of receptive vocabulary in children with autism spectrum disorders. Augmentative and alternative communication, 30(2), 147–159. [PubMed: 24773020]

Cattani A, Abbot-Smith K, Farag R, Krott A, Arreckx F, Dennis I, & Floccia C (2014). How much exposure to English is necessary for a bilingual toddler to perform like a monolingual peer in language tests? International journal of language and communication disorders, 49(6), 649–671. [PubMed: 25039327]

Cauley KM, Golinkoff RM, Hirsh-Pasek K, & Gordon L (1989). Revealing hidden competencies: A new method for studying language comprehension in children with motor impairments. American journal on mental retardation, 94(1), 53–63. [PubMed: 2751891]

Chita-Tegmark M, Arunachalam S, Nelson CA, & Tager-Flusberg H (2015). Eye-tracking measurements of language processing: Developmental differences in children at high risk for ASD. Journal of autism and developmental disorders, 45(10), 3327–3338. [PubMed: 26109246]

Dunn LM, & Dunn DM (2007). PPVT-4: Peabody Picture Vocabulary Test. Pearson Assessments.

Eyer JA, Leonard LB, Bedore LM, McGregor KK, Anderson B, & Viescas R (2002). Fast mapping of verbs by children with specific language impairment. Clinical linguistics & phonetics, 16(1), 59–77. [PubMed: 11913032]

Fernald A, Pinto JP, Swingley D, Weinbergy A, & McRoberts GW (1998). Rapid gains in speed of verbal processing by infants in the 2nd year. Psychological science, 9(3), 228–231.

Fernald A, Perfors A, & Marchman VA (2006). Picking up speed in understanding: Speech processing efficiency and vocabulary growth across the 2nd year. Developmental psychology, 42(1), 98–116. [PubMed: 16420121]

Fernald A, Zangl R, Portillo AL, & Marchman VA (2008). Looking while listening: Using eye movements to monitor spoken language. In Sekerina IA, Fernández EM, & Clahsen H (Eds.), Developmental psycholinguistics: On-line methods in children's language processing (pp. 97–136). Amsterdam: John Benjamins Publishing Company.

Frank MC, Braginsky M, Yurovsky D, & Marchman VA (2016). Wordbank: An open repository for developmental vocabulary data. Journal of child language, 44(3), 677–694. doi: 10.1017/S0305000916000209. [PubMed: 27189114]

Friend M, Schmitt SA, & Simpson AM (2012). Evaluating the predictive validity of the Computerized Comprehension Task: Comprehension predicts production. Developmental Psychology, 48(1), 136. doi:10.1037/a0025511 [PubMed: 21928878]

Gamer M, Lemon J, & Singh IFP (2019). irr: Various coefficients of interrater reliability and agreement. R package version 0.84.1. Retrieved from: https://CRAN.R-project.org/package=irr

Gershon RC, Slotkin J, Manly JJ, Blitz DL, Beaumont JL, Schnipke D, …Weintraub S (2013). IV. NIH Toolbox Cognition Battery (CB): Measuring language (vocabulary comprehension and reading decoding). Monographs of the Society for Research in Child Development, 78(4), 49–69. [PubMed: 23952202]

Gershon RC, Wagster MV, Hendrie HC, Fox NA, Cook KF, & Nowinski CJ (2013). NIH toolbox for assessment of neurological and behavioral function. Neurology, 80(11 Supplement 3), S2–S6. [PubMed: 23479538]

Geytenbeek JJ, Heim MM, Vermeulen RJ, & Oostrom KJ (2010). Assessing comprehension of spoken language in nonspeaking children with cerebral palsy: Application of a newly developed computer-based instrument. Augmentative and alternative communication, 26(2), 97–107. [PubMed: 20497073]

Goldfield BA, Gencarella C, & Fornari K (2016). Understanding and assessing word comprehension. Applied psycholinguistics, 37(3), 529–549. [PubMed: 28490826]

Golinkoff RM, Hirsh-Pasek K, Cauley KM, & Gordon L (1987). The eyes have it: Lexical and syntactic comprehension in a new paradigm. Journal of child language, 14(1), 23–45. [PubMed: 3558524]

Golinkoff RM, De Villiers JG, Hirsh-Pasek K, Iglesias A, Wilson MS, Morini G, & Brezack N (2017). User's Manual for the Quick Interactive Language Screener (QUILS): A Measure of Vocabulary, Syntax, and Language Acquisition Skills in Young Children. Paul H. Brookes Publishing Company.

Hadley PA, Rispoli M, & Hsu N (2016). Toddlers' verb lexicon diversity and grammatical outcomes. Language, speech, and hearing services in schools, 47(1), 44–58.

He AX, & Arunachalam S (2017). Word learning mechanisms. Wiley Interdisciplinary Reviews: Cognitive Science, 8(4), e1435. 10.1002/wcs.1435

He AX, Kon M, & Arunachalam S (2019). Linguistic context in verb learning: Less is sometimes more. Language learning and development. Epub ahead of print. 10.1080/15475441.2019.1676751

Hirsh-Pasek K, & Golinkoff RM (1996). The intermodal preferential looking paradigm: A window onto emerging language comprehension. In McDaniel D, McKee C, & Cairns HS (Eds.), Methods for assessing children's syntax (pp. 105–124). Cambridge, MA, US: The MIT Press.

Hollich G, Hirsh-Pasek K, & Golinkoff RM (2000). Breaking the language barrier: An emergentist coalition model for the origins of word learning. Society for Research in Child Development Monograph Series. Chicago: University of Chicago Press.

Hollingshead AB (1975). Four factor index of social status. Unpublished manuscript, Yale University, New Haven, CT.

Horvath S, & Arunachalam S (Submitted). Individual differences in eye-gaze measures of receptive vocabulary.

Horvath S (2019). The verb vocabularies and verb-learning mechanisms of late talkers. Doctoral dissertation, Boston University.

Hurtado N, Marchman VA, & Fernald A (2008). Does input influence uptake? Links between maternal talk, processing speed and vocabulary size in Spanish-learning children. Developmental science, 11(6), F31–F39. [PubMed: 19046145]

Hurtado N, Grüter T, Marchman VA, & Fernald A (2014). Relative language exposure, processing efficiency and vocabulary in Spanish–English bilingual toddlers. Bilingualism: Language and cognition, 17(1), 189–202.

Huttenlocher J, Smiley P, & Charney R (1983). Emergence of action categories in the child: Evidence from verb meanings. Psychological review, 90(1), 72–93.

Konishi H, Stahl AE, Golinkoff RM, & Hirsh-Pasek K (2016). Individual differences in nonlinguistic event categorization predict later motion verb comprehension. Journal of experimental child psychology, 151(1), 18–32. [PubMed: 27139436]

Law F, Mahr T, Schneeberg A, & Edwards J (2017). Vocabulary size and auditory word recognition in preschool children. Applied psycholinguistics, 38(1), 89–125. [PubMed: 28439144]

Lew-Williams C, & Fernald A (2007). Young children learning Spanish make rapid use of grammatical gender in spoken word recognition. Psychological science, 18(3), 193–198. [PubMed: 17444909]

Mahr T, & Edwards J (2018). Using language input and lexical processing to predict vocabulary size. Developmental science, 21(6), e12685. [PubMed: 29781230]

Marchman VA, & Fernald A (2008). Speed of word recognition and vocabulary knowledge in infancy predict cognitive and language outcomes in later childhood. Developmental science, 11(3), F9–F16. [PubMed: 18466367]

Martarelli CS, & Mast FW (2011). Preschool children's eye-movements during pictorial recall. British Journal of Developmental Psychology, 29(3), 425–436.

McGraw KO, & Wong SP (1996). Forming inferences about some intraclass correlation coefficients. Psychological methods, 1(1), 30–46.

McMurray B, Munson C, & Tomblin JB (2014). Individual differences in language ability are related to variation in word recognition, not speech perception: Evidence from eye movements. Journal of speech, language, and hearing research, 57(4), 1344–1362.

Micalizzi L, Brick LA, Flom M, Ganiban JM, & Saudino KJ (2019). Effects of socioeconomic status and executive function on school readiness across levels of household chaos. Early childhood research quarterly, 47, 331–340. [PubMed: 31341348]

Miller CA, Kail R, Leonard LB, & Tomblin JB (2001). Speed of processing in children with Specific Language Impairment. Journal of speech, language, and hearing research, 44(2), 416–433.

Mittler P (1970). Biological and social aspects of language development in twins. Developmental Medicine & Child Neurology, 12(6), 741–757. 10.1111/j.1469-8749.1970.tb07864.x [PubMed: 5530915]

Naigles LR (1997). Are English-speaking one-year-olds verb learners, too? In Clark E (Ed.), Proceedings of the 28th annual Child Language Research Forum (pp. 199–212). Stanford, CA: CSLI

Naigles LR, & Hoff E (2006). Verbs at the very beginning: Parallels between comprehension and input. In Hirsh-Pasek K & Golinkoff RM (Eds.), Action meets word: How children learn verbs (pp. 336–363). Oxford: Oxford University Press.

Olswang LB, Long SH, & Fletcher P (1997). Verbs in the emergence of word combinations in young children with specific expressive language impairment. International journal of language & communication disorders, 32(2), 15–33.

Pace A, Luo R, Hirsh-Pasek K, & Golinkoff RM (2017). Identifying pathways between socioeconomic status and language development. Annual review of linguistics, 3, 285–308.

Peter MS, Durrant S, Jessop A, Bidgood A, Pine JM, & Rowland CF (2019). Does speed of processing or vocabulary size predict later language growth in toddlers? Cognitive psychology, 115, 101238. [PubMed: 31539813]

R Core Team (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from: https://www.r-project.org

Rescorla L (1989). The Language Development Survey: A screening tool for delayed language in toddlers. Journal of speech and hearing disorders, 54(4), 587–599.

Rescorla L, & Achenbach TM (2002). Use of the Language Development Survey (LDS) in a national probability sample of children 18 to 35 months old. Journal of speech, language, and hearing research, 45(4), 733–743.

Rescorla L, Mirak J, & Singh L (2000). Vocabulary growth in late talkers: Lexical development from 2; 0 to 3; 0. Journal of child language, 27(2), 293–311. [PubMed: 10967889]

Rutter M, & Redshaw J (1991). Annotation: Growing up as a twin: Twin-singleton differences in psychological development. Journal of Child Psychology and Psychiatry, 32(6), 885–895. 10.1111/j.1469-7610.1991.tb01916.x [PubMed: 1744192]

Saudino KJ & Ganiban JM (2019). The Boston University Twin Project (BUTP) II. Twin research and human genetics. Advance online publication. 10.1017/thg.2019.58

Swensen LD, Kelley E, Fein D, & Naigles LR (2007). Processes of language acquisition in children with autism: Evidence from preferential looking. Child development, 78(2), 542–557. [PubMed: 17381789]

Trueswell JC, Sekerina I, Hill NM, & Logrip ML (1999). The kindergarten-path effect: Studying on-line sentence processing in young children. Cognition, 73(2), 89–134. [PubMed: 10580160]

Valleau MJ, Konishi H, Golinkoff RM, Hirsh-Pasek K, & Arunachalam S (2018). An eye-tracking study of receptive verb knowledge in toddlers. Journal of speech, language, and hearing research, 61(12), 2917–2933.

van der Lely HKJ (1994). Canonical linking rules: Forward versus reverse linking in normally developing and specifically language-impaired children. Cognition, 51(1), 29–72. [PubMed: 8149716]

Venker CE, & Kover ST (2015). An open conversation on using eye-gaze methods in studies of neurodevelopmental disorders. Journal of speech, language, and hearing research, 58(6), 1719–1732.

Watkins RV, Rice ML, & Moltz CC (1993). Verb use by language-impaired and normally developing children. First Language, 13(37), 133–143.

Weisleder A, & Fernald A (2013). Talking to children matters: Early language experience strengthens processing and builds vocabulary. Psychological science, 24(11), 2143–2152. [PubMed: 24022649]

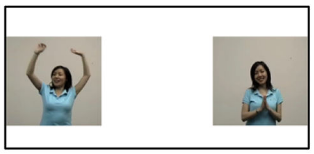
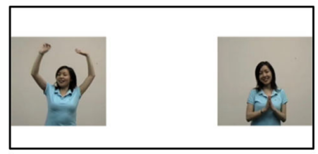
Phase	Familiarization	Response	
Visual Stimuli			
Auditory Stimuli	Do you see?	Where is the corn?	*[ding]* Find the corn! Do you see the corn?
Duration	3 seconds	4 seconds	6 seconds
Visual Stimuli			
Auditory Stimuli	Do you see?	Where is she stretching?	*[ding]* Find stretching! Do you see where she's stretching?
Duration	6 seconds	4 seconds	6 seconds

Figure 1.

Schematic depiction of one noun trial (top) and one verb trial (bottom).

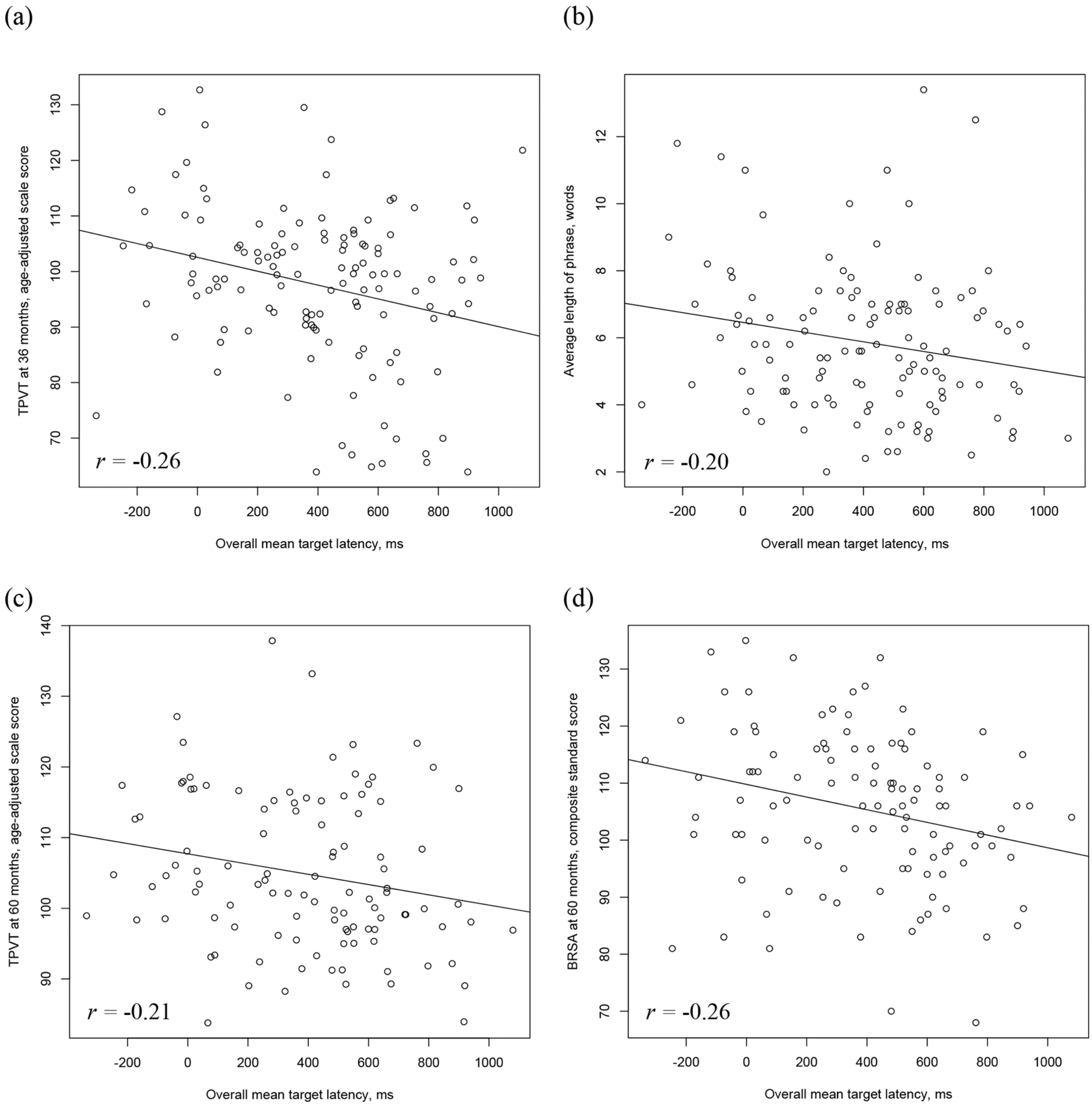


Figure 2.

Scatterplots and correlation coefficients for overall target latency and standardized measures: (a) TPVT (NIH Toolbox Picture Vocabulary Test) at 36 months, (b) TPVT at 60 months, (c) average length of phrase at 36 months, and (d) BSRA (Bracken School Readiness Assessment) at 60 months.

Table 1.

Descriptive statistics for lexical processing task and standardized assessment measures.

	N	*M*	*SD*	Min	Max
Participant means of overall latency (in ms)	126	395.15	302.01	−335.90	1079.49
Noun trials only	126	255.75	354.79	−710.05	1014.29
Verb trials only	126	558.82	367.00	−453.33	1394.44
TPVT at 36 months age-adjusted standard score	126	97.61	14.30	63.92	132.69
TPVT at 60 months age-adjusted standard score	108	104.91	10.86	83.79	137.85
LDS average length of phrase, in words (age 36 months)	119	5.87	2.21	2.00	13.40
BSRA composite standard score (age 60 months)	109	105.48	13.50	68	135

Note. TPVT, NIH Toolbox Picture Vocabulary Test; LDS, Language Development Survey; BSRA, Bracken School Readiness Assessment

Table 2.

Model predicting TPVT (NIH Toolbox Picture Vocabulary Test) at 36 months from target latency (overall, nouns only, verbs only) and demographic factors.

Parameter	Estimate	SE	*t*	*p*
Models: All trials				
Intercept	97.88	14.98	6.53	< .001 *
Overall Target Latency	−0.018	0.0042	−2.79	0.0062 *
SES	0.16	0.14	1.14	0.26
Sex	1.46	2.58	0.57	0.57
Ethnicity	−1.69	7.19	−0.23	0.82
Race	−1.20	2.33	−0.51	0.61
Twin Birth Order	0.13	2.56	0.049	0.96
Model: Noun trials only				
Intercept	98.18	15.25	6.44	<.001 *
Noun Target Latency	−0.0090	0.0037	−2.43	0.017 *
SES	0.15	0.15	1.033	0.30
Sex	1.68	2.60	0.65	0.52
Ethnicity	−3.82	7.30	−0.52	0.60
Race	−1.29	2.36	−0.55	0.58
Twin Birth Order	0.43	2.59	9.17	0.87
Model: Verb trials only				
Intercept	92.41	14.82	6.24	<.001 *
Verb Target Latency	−0.0081	0.0035	−2.31	0.023 *
SES	0.20	0.15	1.36	0.18
Sex	1.87	2.60	0.72	0.47
Ethnicity	0.29	7.31	0.039	0.97
Race	−0.86	2.35	−0.37	0.72
Twin Birth Order	−0.54	2.58	−0.21	0.83

* $p < .05$

Table 3.

Model predicting LDS (Language Development Survey) average length of phrase at 36 months from overall target latency and demographic factors.

Parameter	Estimate	SE	*t*	*p*
Model: All trials				
Intercept	2.31	2.47	0.94	0.35
Overall Target Latency	−0.0011	0.00067	−1.68	0.096
SES	0.046	0.023	2.027	0.045 *
Sex	0.55	0.41	1.36	0.18
Ethnicity	−0.60	1.28	−0.47	0.64
Race	0.32	0.36	0.89	0.38
Twin Birth Order	0.033	0.40	0.082	0.93
Model: Verb trials only				
Intercept	1.59	2.42	0.66	0.51
Verb Target Latency	−0.00060	0.00055	−1.10	0.27
SES	0.050	0.023	2.18	0.032 *
Sex	0.60	0.41	1.48	0.14
Ethnicity	−0.38	1.29	−0.30	0.77
Race	0.36	0.36	0.99	0.32
Twin Birth Order	−0.025	0.41	−0.060	0.95

* $p < .05$

Table 4.

Model predicting TPVT (NIH Toolbox Picture Vocabulary Test) at 60 months from overall target latency and demographic factors.

Parameter	Estimate	SE	*t*	*P*
Model: All trials				
Intercept	110.64	12.30	9.00	< .001 *
Overall Target Latency	−0.0073	0.0034	−2.16	0.033 *
SES	0.21	0.11	1.86	0.066
Sex	−2.39	2.13	−1.12	0.26
Ethnicity	−7.59	5.46	−1.40	0.17
Race	−0.59	1.96	−0.30	0.76
Twin Birth Order	−0.92	2.10	−0.44	0.66
Model: Noun trials only				
Intercept	110.19	12.43	8.87	<.001 *
Noun Target Latency	−0.0054	0.0030	−1.84	0.068
SES	0.20	0.12	1.74	0.084
Sex	−2.23	2.14	−1.044	0.30
Ethnicity	−8.75	5.53	−1.58	0.12
Race	−0.50	1.97	−0.25	0.80
Twin Birth Order	−0.74	2.13	−0.35	0.73
Model: Verb trials only				
Intercept	107.49	12.19	8.82	<.001 *
Verb Target Latency	−0.0049	0.0029	−1.71	0.091
SES	−.23	0.11	2.046	0.043 *
Sex	−2.16	2.14	−1.010	0.31
Ethnicity	−6.45	5.54	−1.16	0.25
Race	−0.44	1.97	−0.22	0.82
Twin Birth Order	−1.38	2.12	−0.65	0.51

* $p < .05$

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Table 5.

Model predicting TPVT (NIH Toolbox Picture Vocabulary Test) at 60 months from overall target latency, demographic factors and TPVT at 36 months.

Parameter	Estimate	SE	*t*	*p*
Model: All trials				
Intercept	100.44	14.44	6.95	< .001*
Overall target latency	−0.0060	0.0035	−1.74	0.085
TPVT at 36 months	0.098	0l073	1.33	0.19
SES	0.20	0.11	1.78	0.078
Sex	−2.47	2.12	−1.16	0.25
Ethnicity	−7.51	5.44	−1.38	0.17
Race	−0.45	1.96	−0.23	0.82
Twin birth order	−0.78	2.10	−0.37	0.71

*$p < .05$

Table 6.

Model predicting BRSA (Bracken School Readiness Assessment) scores at 60 months from overall target latency and demographic factors at 36 months.

Parameter	**Estimate**	**SE**	***t***	***p***
Model: All trials				
Intercept	83.30	14.88	5.60	< .001 *
Overall Target Latency	−0.010	0.0041	−2.45	0.016 *
SES	0.41	0.14	2.97	0.0037 *
Sex	−0.18	2.56	−0.071	0.94
Ethnicity	0.66	6.62	0.10	0.92
Race	1.11	2.38	0.47	0.64
Twin Birth Order	−0.52	2.53	−0.21	0.84
Model: Noun trials only				
Intercept	83.84	14.93	5.62	<.001 *
Noun Target Latency	−0.0087	0.035	−2.46	0.016 *
SES	0.39	0.14	2.81	0.0059 *
Sex	−0.032	2.55	−0.013	0.99
Ethnicity	−1.32	6.68	−0.20	0.84
Race	1.17	2.38	0.49	0.62
Twin Birth Order	−0.17	2.54	−0.067	0.95
Model: Verb trials only				
Intercept	78.70	14.84	5.30	<.001 *
Verb Target Latency	−0.0060	0.0034	−1.74	0.084
SES	0.44	0.14	3.14	0.0022 *
Sex	0.17	2.59	0.064	0.95
Ethnicity	2.12	6.76	0.31	0.75
Race	1.33	2.41	0.55	0.58
Twin Birth Order	−1.086	2.57	−0.42	0.67

* $p < .05$

Table 7.

Model predicting BRSA (Bracken School Readiness Assessment) scores at 60 months from overall target latency, demographic factors, and TPVT (NIH Toolbox Picture Vocabulary Test) at 36 and at 60 months.

Parameter	Estimate	SE	*t*	*p*
Model: All trials, TPVT at 36 months as a predictor				
Intercept	44.86	15.93	2.82	0.0058 *
Overall Target Latency	−0.0052	0.0039	−1.34	0.18
TPVT at 36 months	0.38	0.082	4.63	< .001 *
SES	0.37	0.13	2.94	0.0041 *
Sex	−0.92	2.35	−0.39	0.70
Ethnicity	1.039	6.048	0.17	0.86
Race	1.57	2.17	0.72	0.47
Twin Birth Order	−0.26	2.31	−0.11	0.91
Model: All trials, TPVT at 60 months as a predictor				
Intercept	66.36	20.35	3.26	0.015
Overall Target Latency	−0.0087	0.0042	−2.067	0.041 *
TPVT at 60 months	0.15	0.12	1.22	0.23
SES	0.38	0.14	2.68	0.0087 *
Sex	0.29	2.63	0.11	0.91
Ethnicity	1.81	6.74	0.27	0.79
Race	1.20	2.40	0.50	0.62
Twin Birth Order	−0.46	2.58	−0.18	0.86
Model: Noun trials only, TPVT at 60 months as a predictor				
Intercept	66.88	20.37	3.28	0.0014 *
Noun Target Latency	−0.0077	0.0037	−2.11	0.037 *
TPVT at 60 months	0.15	0.12	1.25	0.21
SES	0.36	0.14	2.53	0.013 *
Sex	0.33	2.62	0.13	0.90
Ethnicity	0.12	6.82	0.017	0.99
Race	1.24	2.39	0.52	0.61
Twin Birth Order	−0.15	2.59	−0.059	0.95
Model: Verb trials only, TPVT at 60 months as a predictor				
Intercept	59.25	19.97	2.97	0.038 *
Verb Target Latency	−0.0052	0.0036	−1.45	0.15
TPVT at 60 months	0.18	0.12	1.44	0.15
SES	0.71	0.14	2.78	0.0065 *
Sex	0.71	2.64	0.27	0.79
Ethnicity	3.26	6.83	0.48	0.63
Race	1.42	2.42	0.59	0.56
Twin Birth Order	−0.92	2.61	−0.35	0.72

[*] $p < .05$

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