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Touch Screen Assessment of At-Risk Infant Comprehension

Rachel Elizabeth Hahn Arkenberg
Purdue University

TOUCH SCREEN ASSESSMENT OF AT-RISK INFANT COMPREHENSION

by

Rachel Elizabeth Hahn Arkenberg

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STATEMENT OF COMMITTEE APPROVAL

Dr. Amanda Seidl, Chair

Department of Speech, Language, and Hearing Science

Dr. Laurence Leonard

Department of Speech, Language and Hearing Science

Dr. Françoise Brousseau-Lapré

Department of Speech, Language and Hearing Science

Approved by:

Dr. Amanda Seidl

Head of the Graduate Program

To my family who beautifully loves, supports, and challenges me: Matthew, Mom, Dad, Michael, and Grandpa.

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ABSTRACT

Author: Hahn Arkenberg, Rachel, E. MS
Institution: Purdue University
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Major Professor: Amanda Seidl

Purpose: There are few clinical tools available to productively assess comprehension in children under 20 months. The Computerized Comprehension Task (CCT) is a valid and reliable measure (Friend and Keplinger, 2003), but it has never been studied in children who are at risk for speech and language disorders. This study seeks to measure the effectiveness of the CCT in assessing high risk infants and evaluate the relationship between scores on the CCT and performance on a standardized language measure 6 months later.

Method: Eleven high risk infants (categorized as “high risk” for genetic risk factors or pre-term birth) and eleven matched peers (14-24 months) completed standardized and non-standardized tests of speech and language at two time points six months apart. Performance on tasks was compared between risk groups and between assessment measures.

Results: Performance on the CCT was significantly correlated with standardized receptive language measures, and high risk infants performed differently than their low-risk peers. The CCT was also significantly correlated with language production 6 months later.

Conclusions: The CCT is an effective measure of comprehension for high risk infants, and CCT scores are related to language production outcomes six months later.

INTRODUCTION

Understanding the early development of children who will go on to develop speech and language disorders is a priority for the field of Speech-Language Pathology since early diagnosis and subsequent intervention can have a significant impact on later personal and academic growth (Aram & Hall, 1989; Berkman & Wallace, 2015; Lewis et al., 2011). Comprehension is a crucial component of language development in children and is a reliable measure of their language competence (Bornstein & Haynes, 1998). Further, assessment of comprehension allows for assessment at a younger age than speech production since perception precedes production and lacks confounds associated with the protracted development of motor skills (Davis & MacNeilage, 1990; Hale &Reiss, 1998). However, there are few clinical tools available to assess comprehension in children under 20 months, and those that exist are time consuming to administer and require a high degree of clinician training (e.g., the Mullen scales; Mullen, 1995).

Recently constructed assessments, such as the Comprehension Book (Ring and Fenson, 2000) and the Computerized Comprehension Task (CCT; a touch screen tool for assessing comprehension; Friend and Keplinger, 2003) have been explored for use in typically developing children. Results reveal the CCT to be valid, reliable, predictive, and to increase levels of infant compliance compared to the Comprehension Book. Further investigation is needed to determine whether the CCT would be a viable tool for children who are at risk for speech and language disorders for genetic, demographic, or developmental reasons and whether such measures are good predictors of atypical outcomes. Children who are at risk for speech and language disorders are the children most in need of screening and assessment in order to provide opportunities for early intervention, so it is important to evaluate the use of comprehension assessment tools in this population. The current study explores whether the CCT is useful in assessing young children who are at risk for speech and language disorders. As a secondary question, we also ask whether this task is predictive of performance on a standardized language measure 6 months later.

Prevalence of speech and language disorders

Speech and language disorders and delays diagnosed in young children often lead to academic problems later in development (Aram & Hall, 1989; Bishop & Adams, 1990; Lewis, Freebairn, & Taylor, 2000). More specifically, children with SSD are at risk for delayed phonological awareness and literacy skills. These may lead to difficulties in reading (Bird, Bishop, & Freeman, 1995; Larrivee & Catts, 1999; Raitano et al., 2004, Rvachew, Ohberg, Grawburg, & Heyding, 2003). Thus, speech and language development in early childhood is a vital piece of academic success.

Approximately 16% of children display Speech Sound Disorders (SSD) at 3 years of age (Campbell et al., 2003), and 3.8% of children still have SSD at 6 years of age (Shriberg, Tomblin, & McSweeney, 1999). The prevalence of Specific Language Impairment (SLI) is approximately 7% in 5-year-olds (Tomblin et al., 1997), and SLI often co-occurs with SSD (Pennington & Bishop, 2009). However, the prevalence of speech and language delay is higher still in children who are at risk for such delays and disorders.

Children can be at risk for speech and language delays for a variety of reasons, including genetics (e.g., having a family member with a speech/language disorder; Lewis, et al. 2006; Lewis et al. 2011), preterm birth (McGowan, Alderice, Holmes, & Johnston, 2011; Sansavini et al. 2011), and demographic factors (Hart & Risley, 1995; Hoff, 2003; Jyoti, Fongillo, & Jones, 2005). Though speech and language disorders are etiologically complex due to heterogeneous and changing phenotypes, genetic connections have been established through twin studies, familial aggregation, and molecular genetic studies (Lewis, et al. 2006). Not only do SSD, SLI, and Reading Disorders (RD) display genetic connections independently, Lewis et al., (2006) also found that there are genetic traits in common between SSD and RD in a linkage study. More recently, specific cognitive skills (endophenotypes) have been found to be particularly useful for studying genetic predictors of later literacy. Lewis et al., (2011) completed genetic linkage analyses that confirmed a common genetic basis for both the childhood endophenotypes and later spoken language and literacy skills and school-aged academic outcomes. These commonalities demonstrate the overlapping genetic basis of speech and language disorders and point to a large group of children at risk for speech and language disorders: children or siblings of individuals who have already been diagnosed with SSD, SLI, and/or a RD.

Another group of children with well-established risk for later speech and language disorders are preterm infants. Sansavini et al. (2011) found that very preterm infants (mean gestational age 29.5 weeks), demonstrated a slower rate of cognitive-linguistic development as compared to their full-term peers. In the second year of life, toddlers who were born preterm had increasing differences when compared to full-term peers in gestural and lexical complexities. Even late preterm infants (born at 34-36 weeks gestation), are at risk for adverse developmental outcomes. A systematic review found that late preterm infants were at risk for developmental and academic delays up to 7 years of age in comparison to full-term infants (McGowan, Alderice, Holmes, & Johnston, 2011). In sum, though the prevalence of speech and language disorders in the general population is fairly low, the prevalence in these at risk groups is higher. Thus, an effective strategy in testing the viability of an assessment method would utilize these higher risk groups to explore whether (a) the assessment is still valid with high risk children and (b) whether it can diagnose-early children with speech and language delays and disorders.

Early assessment and diagnosis is essential since early screening and intervention has been shown to improve outcomes for children who are at risk for both SSD and SLI (Nelson, Nygren, Walker, & Panoshca, 2006). In a systematic review focused on screening for speech and language delays, prepared for the U.S. Department of Health and Human Services, Berkman and Wallace (2015) examined novel and previously identified treatment evidence for language, speech sounds, and fluency. They found that interventions for speech and language disorders improve speech and language outcomes for both toddlers and preschoolers across a variety of studies, including eight randomized controlled trials examining interventions. If children are identified as being at risk for a speech or language disorder, they could be screened and, if necessary, receive intervention, thus improving speech and language skills and preventing any associated delays.

Comprehension and Production

Though the relationship between language comprehension and production has been fraught with controversy over the last 50 years (e.g., Benedict, 1979; Snyder, Bates, & Bretherton, 1981; Bates, Benigini, Bretherton, Camaioni, & Voltera, 1979), recent work has demonstrated that there may be continuity and connections between comprehension and production. A study by Feldman et al. (2000) reported significant correlations between parent reports of comprehension and production on the CDI at 1-2 years of age, in a large, diverse sample. A more recent study by Feldman et al. (2006) indicated that vocabulary scores at 2 years predict language skills at 3 years. In another study that supports the continuity of perception and production, Kuhl (2009) demonstrated that infant perception of native and non-native contrasts at 7 months is related to their vocabulary size at 24 months. On the flip side, Majarano, Vihman, and DePaolis (2013) showed that production affects speech perception in infants by demonstrating a relationship between infant preverbal production and attentional responses to vocal motor schemes.

Not only has it been shown that comprehension and production are related, there is evidence that comprehension skill is able to predict production. Marchman and Fernald (2008) found that the speed of children's shifts in attention to a labeled object in a looking task at 25 months predicts language outcomes at 8 years. Similarly, Tsao, Liu, and Kuhl (2004) demonstrated that speech perception at 6 months is significantly correlated with language production in the second year. Taken together, these studies demonstrate not only continuity between comprehension and production, but the potential for using comprehension to predict production. Combining these studies with data from Rvachew and Grawberg (2006), which indicates increased risk for children with SSD who also have poor speech perception and receptive vocabulary, comprehension appears to be a particularly important domain to consider in children at risk for speech and language disorders.

Assessing Comprehension and Production at a Young Age

Several measures exist to assess language production in infancy, but due to practical difficulties, there are few measures outside of a laboratory setting (e.g., preferential looking/looking-while-listening/eye-tracking) that directly examine comprehension. Currently, most comprehension and production studies in infancy have focused on typically-developing children who are not at risk for disorders, which leads to the need for the current study exploring the viability of using a short tablet-based task with children who are at risk for speech and language disorders.

The most commonly used measure of infant comprehension is an indirect measure of infants' comprehension of vocabulary. The MacArthur Communicative Development Inventory (CDI; Fenson et al., 1993) was developed as a standardized measure for *parents* to report infant comprehension and production of words. Though the CDI is widely used and has been translated into many languages, its reliability, validity, and utility have been widely criticized. Feldman, et al. (2000) criticized the amount of variability, lack of stability, and inability to predict early language delay. Fenson et al. (2000) responded to these critiques by asserting that individual differences reflect real trends in early language growth, that there is no theoretical reason to expect stability in children under 2 years, and that the CDI is not meant to be predictive until individual differences stabilize. Regardless of the reliability, validity, and utility of the CDI, it is valuable to utilize performance-based measures of comprehension to augment parental report since some parents may under-report and some parents may over-report. Particularly for children who are at risk for language delays and disorders, we predict that direct measures may be better predictors of outcomes than indirect ones.

As mentioned, there are direct measures of comprehension used in the lab such as preferential looking. Preferential looking assesses visual fixation as a dependent measure of lexical association (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987). Preferential looking tasks give useful information about comprehension, but they also present limitations. Their format limits presentation to few items, and they are used in laboratory settings, which means they are not widely available for clinicians. Further, coding and analyzing recordings of infant data requires a high degree of training not available to most clinicians working with at risk populations.

The Computerized Comprehension Task

Friend and Keplinger (2003) developed a performance-based comprehension measure designed to create a high level of infant compliance and ease of administration. The CCT is a touchscreen program comprised of 41 high quality picture pairs presented in a forced-choice format, based on the original Comprehension Book (Ring & Fenson, 2000). Friend and Keplinger (2003) extended the original format by randomizing word difficulty across trials (so that inattention would not be cofounded with lack of knowledge), improving images, and incorporating more difficult words to extend the ceiling of the assessment. In order to increase attention, Friend and Keplinger used colorful, attractive images presented in a touch screen format. Also, they added reinforcing auditory signals, which are produced by touches to the target image. The combination of attractive visual and auditory stimuli activated in response to infant touch is common in educational toys, which makes the CCT a familiar and engaging approach. In their preliminary study, Friend and Keplinger found that infants correctly identified targets significantly more often on the CCT than the Comprehension book, the data largely mirrored parent report, and individual data demonstrated consistent performance across tasks (Friend & Keplinger, 2003). Recently, the CCT has been utilized to assess comprehension in monolingual and bilingual infants with the eventual aim of evaluating if the CCT can predict developmental risk in a cross-linguistic sample (Legacy, Poulin-Dubois, Zesiger, & Friend, 2014).

Friend, Schmitt, & Simpson (2012) investigated the convergent and predictive validity of the CCT compared with the CDI: Words and Gestures (CDI:WG). Final data analyses were completed on 50 infants (16;2-21;4 months). Vocabulary comprehension scores did converge with parental reports, and they established test-retest reliability. In a second study published in the same paper, Friend, Schmitt, and Simpson (2012) studied the predictive capabilities of the CCT and CDI. Twenty-five children between 24 and 41 months from the first study returned for evaluation 6 to 20 months later. Both the CDI:WG and CCT scores served as predictors of language production based on their strong correlation with reported production on the CDI: Words and Sentences (CDI:WS). However, the CCT not only predicted parent reports of language production on the CDI:WS, it also accounted for greater variance (24% of the variance in children's unique word use and 13% of unique variance) as compared to the CDI:WG (16% and 4% respectively). The parent report on the CDI:WG was superior to the CCT as a predictor of sentence complexity. Though both the parent report on CDI:WG and the CCT were predictive, the CCT was a stronger predictor of vocabulary in terms of unique words. This may be because direct assessments assess word knowledge without context. These results indicate that the CCT is a valid and reliable performance-based test of comprehension with potential advantages over the parent-reported CDI:WG.

The CCT has been studied and shown to be useful in assessing monolingual and bilingual young children, but it has not been examined with children who are at risk for speech and language disorders. If comprehension at a very young age could predict later speech and language development, it would be valuable to have a tool that could quickly and accurately assess comprehension. The CCT has been established as a valid and reliable performance-based comprehension test from infants under 20 months, however, it has not been specifically tested with children who are at risk for speech and language disorders. The current study seeks to examine if performance on the CCT differs for children between 14-24 months who are at risk for speech and language disorders as compared to matched peers who do not have risk factors and to examine whether performance on the CCT is predictive of performance on standardized language measures gathered 6 months later.

METHODS

Participants

Participants were 11 high- and 11 low-risk 14- to 24-month-olds individually matched for age and Socio-Economic Status (SES). Qualifications for being placed in the high-risk group were having a family history (sibling or parent with a speech or language disorder) or a history of preterm birth. Low-risk participants for this study were recruited from a university-specific database consisting of birth records of typically developing children born in the area. High-risk participants were recruited by sending information about the study to Speech Language Pathologists, by contacting siblings of participants in research studies for children with speech and language disorders, and searching the previously mentioned database for preterm infants. Table 1 shows the age and demographic information for each risk group, including rationale for risk group placement.

Table 1. *Participant Characteristics*

Age	Mother's Education (years)	Hearing Screening (OAE)	Reason for Risk
17.57	16	Pass	Sibling with SLI and SSD
14.64	15	Pass	Sibling with SSD
18.39	16	R pass, L poor seal	Sibling with SSD
15.00	16	Pass	Sibling with SSD
23.55	16	Pass	Sibling with SLI
16.12	16	Pass	Preterm Birth
15.03	16	Pass	Sibling with SLI and SSD
23.5	19	Pass	Sibling with SLI and SSD
15.69	18	Pass	Sibling with SSD
15.66	12	Pass	Sibling with SLI and SSD
19.97	16	Pass	Preterm Birth
23.85	16	Pass	Low risk
17.11	16	Pass	Low risk
14.84	16	Pass	Low risk
19.14	16	Pass	Low risk
15.39	20	Pass	Low risk
19.47	16	Pass	Low risk
23.32	13	Pass	Low risk
18.75	18	Pass	Low risk
15.69	18	Pass	Low risk
13.98	18	Pass	Low risk
14.74	12	Pass	Low risk

Procedure

Participants completed the study in three visits to the laboratory. During the first visit, parents and infants were introduced to the study and provided informed consent, and infant hearing was screened using otoacoustic emissions (Otoport OAE, Otodynamics). Next, participants completed a short production task in order to assess consonants in the child's phonemic inventory. Toys were taken out of a bag and described by saying, "This is a ____," and child repetitions of consonants in target words were transcribed phonetically. Words were selected to reflect a variety of consonants across word positions (3 stops, 1 nasal, 1 liquid, and 3 fricatives), and a variety of word structures, including CVC, VCVC, and CVCVCV. All target words were selected based on production norms from WordBank (Frank, Braginsky, Yurovsky,

& Marchman, 2016). Words were only selected if they were produced by more than 50% of children at 18 months. Each target word was elicited with three different toy exemplars (e.g., three different dogs) and responses were audio-recorded (Shure PGXD1 Bodypack Transmitter and Shure PGXD4 Wireless Receiver) to obtain a phonetic inventory from transcription (See Table 2).

Table 2 *Target Phonemes and Word Frames.*

Object	Ball	Dog	Cat	Sock	Keys	Banana	Fish	Apple	Duck
Phonemes Assessed	b l	d g	k t	s k	k z	b n	f sh	p l	d k

Before administering the CCT, 5 training trials were completed to introduce children to the touchscreen task. During training trials, the examiner gave the child specific directions, modeled screen touches, and used a hand-over-hand technique to introduce the touch screen if the child did not touch when prompted. Then, the child completed the CCT according to standardized administration procedures described in Friend and Keplinger (2003). This included the child giving haptic responses to verbal prompts from the examiner such as, “Where is the ____?”. At the end of the CCT, reliability testing was attempted. All reliability trials had target objects placed on the opposite side that they occurred in during the original elicitation (e.g., if the target for “dog” was on the right during the original elicitation, it was on the left for reliability). Because 20 infants were non-compliant in reliability, these data were not examined in statistical analyses.

During the second test session, participants completed 3 sub-scales from the Mullen Scales of Early Learning (Mullen, 1995). The Mullen is a standardized test which measures areas of strength and weakness in cognitive ability and motor development. Each section of the Mullen takes approximately 10-20 minutes to complete and score, meaning the entire test takes 50-100 minutes. It generates reliable and valid information regarding early development (Mullen, 1995). Only the three of the scales that we deemed most related to language development and touch screen use were used in this study (fine motor, receptive language, and expressive language).

Six months after their initial testing date, participants returned for a six-month follow up appointment, in which they completed the CCT and the two language sub-scales of the Mullen scales.

Stimuli

Visual stimuli for the CCT include 90 high-quality digital images, which are prototypical referents for lexical targets controlled for salience. Verbal prompts for each trial were produced by the experimenter, using the same prompt for each word class (See Appendix). Each target image is associated with an auditory stimulus of the lexical item produced in child-directed speech and a reinforcing sound. The sound is presented after the infant touches the target as a motivator for engagement with the task.

RESULTS

To answer our primary question focused on performance of high risk infants on the CCT, consonantal inventory, Mullen Raw and Standard Scores on the three subtests, and performance on the CCT (number correct) were calculated for each participant after their first two visits (time 1). To determine each participant's phonemic inventory, all utterances were transcribed phonetically and the number of total consonants in the inventory was calculated (Mean = 8.54, Range = 5-16). Raw and standard scores were collected from three subtests of the Mullen (Mullen,1995). Since the CCT is not normed for standard scores, it was scored by number correct responses (Mean = 16.72; Range = 5-26). Infant Sensitive screen areas encompass less than 50% of the screen area, so random touches have a low probability of being counted as correct.

After the third visit six months later, (time 2) Mullen Raw Scores on two language subtests (Receptive and Expressive language) and performance on the CCT (number correct) were calculated for 19 of 22 original participants (two participants moved out of state and one was unable to be contacted). As demonstrated in Table 3, the high risk group received lower average scores for all measures at time 2, as expected, but only the CCT was consistent with this pattern at time 1.

Table 3. *Average Scores by risk group at time 1 and time 2.*

	Mullen: Fine Motor	Mullen: Receptive	Mullen: Expressive	Phonetic Inventory	CCT
High-Risk (T1)	62.55	17.64	17.55	8.54	15
Low-Risk (T1)	60.09	17.18	16.91	8.54	18.45
High-Risk (T2)	-	21.5	19.5	-	18.5
Low-Risk (T2)	-	23.5	20.5	-	24.5

Note. T1=Time 1, T2=Time 2.

In order to compare performance across tasks, Pearson's multivariate correlations were completed for all assessments. At time 1, score on the CCT was significantly correlated with score on the Mullen Receptive Language subtest, Mullen Expressive Language subtest, and with the phonetic inventory (Table 4*).* As expected, Mullen receptive and Mullen expressive scores were correlated with each other and size of the phonetic inventory (Table 4).

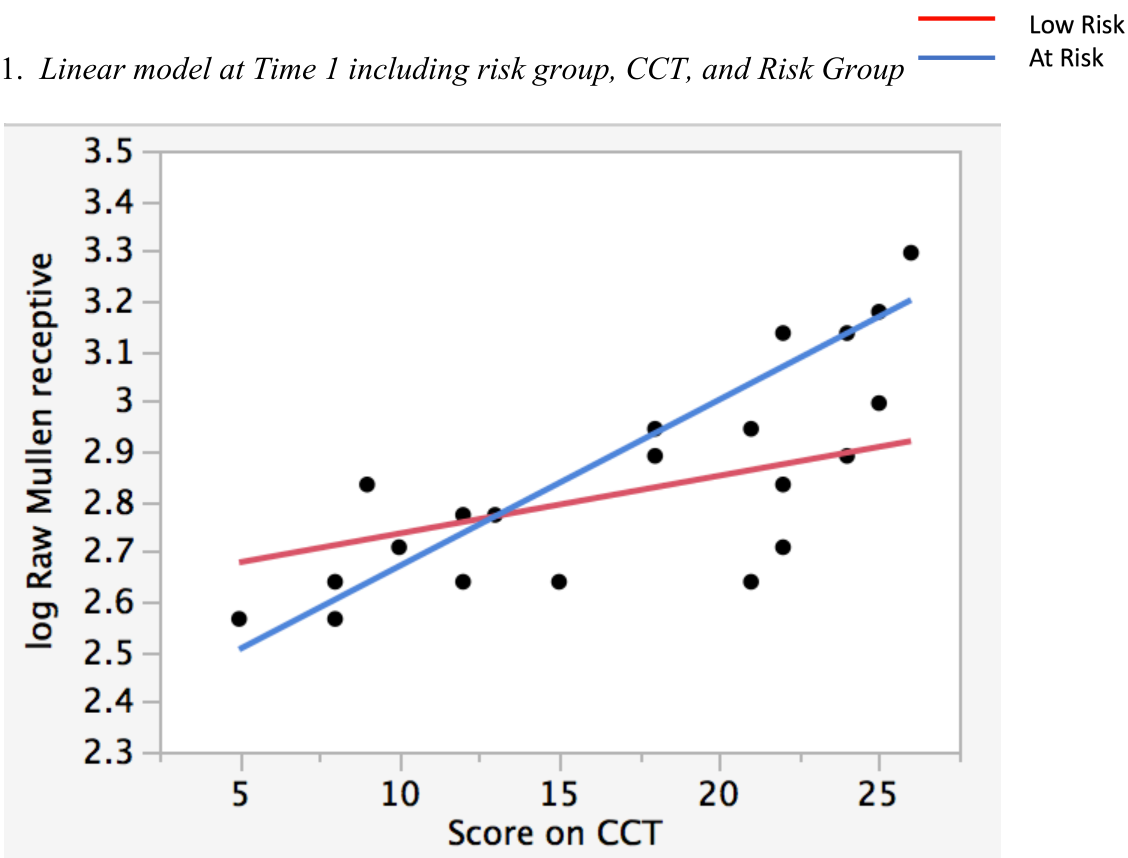
Table 4. *Pearson's Multivariate Correlations – Time 1*

	Mullen Receptive	Mullen Expressive	Mullen Fine Motor	Number in Phon. Inv.	CCT
Mullen Receptive	-				
Mullen Expressive	0.735**	-			
Mullen Fine Motor	0.561*	0.593**	-		
Number in Phon. Inv.	0.731**	.699**	.571**	-	
CCT	0.749**	0.677**	.428*	0.639**	-

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

To compare influence of risk group on receptive language performance, a stepwise linear regression was completed with log raw Mullen receptive scores as the dependent variable. Mullen raw scores were selected for consistency with the use of CCT raw scores (due to lack of normative data on the CCT). Age and development were accounted for by the age-matched sample. Secondary to examination of Box-Cox Transformation, the data was log-transformed to approximate a normal curve due to small sample size. The most significant model of the linear regression is depicted in Figure 1. It included risk group, CCT score, and Risk Group x CCT, which revealed a highly significant interaction.

Figure 1. *Linear model at Time 1 including risk group, CCT, and Risk Group x CCT*



Because of the interaction between risk group and CCT score in the linear regression Figure 1), correlations between Mullen Receptive score and CCT were calculated for each group individually. The high risk group showed a highly significant correlation between CCT and Mullen score, but the low risk group did not demonstrate a significant correlation (Table 5).

Table 5. *Pearson's Correlation of Mullen Receptive and CCT with Significance Values at Time 1*

	Correlation	Significance
High Risk	.958	<.0001**
Low Risk	.434	.183

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

In order to evaluate our second question concerning the relationship between CCT score at the first visit and language outcomes after six months, Pearson's Multivariate Correlations were completed for all measures taken at both time 1 and 2. As seen in Table 6, two-tailed Pearson's correlations revealed that score on the CCT at time 1 was significantly correlated with the following measures at time 2: score on the Mullen Expressive Language subtest, CCT, and Mullen Receptive Language subtest. This indicates that time 1 CCT score was related to both language comprehension and production six months later. As anticipated, Mullen receptive and Mullen expressive scores were correlated with each other and themselves at times 1 and 2. CCT scores at time 2 were also significantly correlated with scores on all tests at times 1 and 2. (Risk groups were not divided for analysis at time 2, because of the low n.)

Table 6. *Pearson's Multivariate Correlations – Times 1 and 2*

	1st Mullen Receptive	1st Mullen Expressive	1st CCT	2nd Mullen Receptive	2nd Mullen Expressive	2nd CCT
T1 Mullen Receptive	-					
T1 Mullen Expressive	.755***	-				
T1 CCT	.771***	.752***	-			
T2 Mullen Receptive	.532*	.570*	.466*	-		
T2 Mullen Expressive	.776***	.807***	778***	.606**	-	
T2 CCT	.598**	.628**	.610**	.674**	.650**	-

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)
*** Correlation is signification at the 0.001 level (2-tailed)

DISCUSSION

The results of our study support the use of the CCT as a measure of language in infants who are at risk for speech and language disorders. The CCT was found to be an effective measure of comprehension in these infants, since it is correlated with standardized receptive language measures. Further, the average performance of high risk infants on the CCT was lower than low risk peers at times 1 and 2. CCT was also shown to be especially telling for the high risk group such that when high and low risk infants were divided for linear regression to predict Mullen scores, the CCT was a better predictor for high risk infants ($p<0.001$), than low risk infants. This may suggest that the CCT is particularly good at capturing the variability in the population that relates to language measures. Similar to previous studies, our data suggests that the CCT is an effective measure of comprehension overall, since it is correlated with Mullen receptive language scores for both risk groups (Friend & Keplinger, 2003; Friend, Schmitt, & Simpson, 2012). Our results indicate that the CCT also gives information related to an infant's expressive language at a given time, given its' high correlation with our phonetic inventory measure and Mullen expressive language scores.

In response to our second question concerning the relationship between CCT scores and language outcomes after six months, our study provides evidence that the CCT, a solely receptive language measure, is as correlated with language production 6 months later (as measured by the Mullen Expressive Language Subtest) as the Mullen scales itself ($p<0.001$). These results demonstrate that the CCT is a viable option to measure a high risk infant's comprehension at a given time, and that comprehension information from the CCT is as related to future language outcomes as a standardized language measure. These factors combined with the practical characteristics of the CCT make it a superior clinical tool when compared to existing measures of comprehension. Measures of comprehension such as the CCT are useful to augment parental report since parent report may include bias, under-reporting, or over-reporting. Friend, Schmitt, and Simpson (2012) reported that the CCT was a stronger predictor of vocabulary and accounted for more variance than the CDI:WG, and it has also been demonstrated as an improvement from the Ring and Fenson (2000) Comprehension book (Friend & Keplinger, 2003). Further, there are practical advantages of the CCT over the Mullen Scales and lab-based measures (preferential looking/looking while listening/eye-tracking) since the CCT is easy to use and efficient and its touch screen format facilitates infant attention and engagement. Further, the CCT requires only one item, a touch screen device, as opposed to the Mullen, which requires a bag of manipulates, or lab-based tools that require dedicated space and specialized equipment. The efficient time frame and simplicity of materials make the CCT easier for clinicians in early intervention, who often travel to homes and must transport materials.

The relationship between comprehension and production exemplified in this study is consistent with previous research that has demonstrated connections between early measures of comprehension and later production outcomes (e.g., Feldman et al., 2006; Kuhl, 2009; Marchman & Fernald, 2008; Tsao, Liu, and Kuhl, 2004). Therefore, clinicians using the CCT to assess comprehension of high risk infants at a very young age (14-20 months) could also use this information to make educated conjectures about the infant's future language development. With further research, such as normative data, the CCT could be utilized as an effective evaluation or screening tool for early identification of children for speech and language disorders. Ideally, a child with known risk factors, such as genetics, preterm birth, or low SES could be assessed with a tool like the CCT at a young age (under 20 months) and begin early intervention if they were not meeting expected milestones. This early intervention could have an immense impact not only on the development of speech and language, but also on academic outcomes for high risk children.

It should be noted that the touch-screen format is ideal for a quick infant assessment, but this format is not intended for use in infant learning. It has been demonstrated that infants have difficulty transferring 2-D, touch-screen learning to real-world situations (Barr, 2013), and the misuse of technological devices during infancy is a public health concern (American Academy of Pediatrics, 2011). The touchscreen format of the CCT is a valuable aspect of its utility as an assessment tool, but it is worth discussing with families the role of technology in their children's learning beyond an initial assessment. The CCT should be utilized for its purpose as an assessment tool, not a therapy tool or activity for infant learning.

This study has several limitations including limited sample size and attrition. Also, we were only able to examine infants at risk due to pre-term birth and genetic risk due to recruitment limitations. SES is a significant risk factor for speech and language development, and it is vital to keep demographic factors in mind when assessing infants. Children with low SES hear fewer words, receive qualitatively different input, and develop vocabulary more slowly (Hart & Risley, 1995; Hoff, 2003; Jyoti, Fongillo, & Jones, 2005). Future studies should include an examination of infants who are high risk due to SES.

With further research, the CCT could be utilized as an evaluation or screening tool for early identification of children for speech and language disorders, which is a priority for both speech-language pathologists and conscientious pediatricians (Nelson, Nygren, Walker, & Panoshca, 2006). However, larger scale longitudinal data exploring both language and academic outcomes is needed. Our primary question was related to the assessment of infants who are high risk, but it is also necessary to evaluate the predictive capabilities of the CCT. We provided data that the CCT is related to language outcomes six months later in both low risk and high risk infants, but studies are needed that extend longer, particularly into the academic years. Additionally, large scale normative data would be necessary to provide standardized scores for clinical utility. Assessment of infants is difficult due to the heterogeneity of early development, but tools such as the CCT provide objective data that can assist in accurate early identification of children who need intervention to support their speech and language development.

REFERENCES

American Academy of Pediatrics. (2011). Media use by children younger than 2 years. Pediatrics, 128, 1040–1045. doi:10.1542/peds. 2011-1753

Aram D. M., Hall N. E. (1989). Longitudinal follow-up of children with preschool communication disorders: Treatment implications. School Psychology

Barr, R. (2013). Memory constraints on infant learning from picture books, television, and touchscreens. *Child Development Perspectives*, *7*(4), 205-210.

Bates, E., Benigni, L., Bretherton, I., Camaioni, L., & Volterra, V. (1979). The emergence of symbols: Cognition and communication in inlancy. New York: Academic Press.

Benedict, H. (1979). Early lexical development: comprehension and production. *Journal of Child Language, 6*(02). doi:10.1017/s0305000900002245

Berkman, N. D., Wallace, I., et al. (2015). Rockville (MD): Agency for Healthcare Research and Quality, (Evidence Synthesis No. 120 [Prepared by RTI International–University of North Carolina Evidence-based Practice Center (EPC) under Contract No. HHSA-290-2012-00015-I, Task Order No. 2]), 210.

Bird, J., Bishop, D. V., & Freeman, N. H. (1995). Phonological Awareness and Literacy Development in Children With Expressive Phonological Impairments. *Journal of Speech Language and Hearing Research, 38*(2), 446. doi:10.1044/jshr.3802.446

Bishop, D. V., & Adams, C. (1990). A Prospective Study of the Relationship between Specific Language Impairment, Phonological Disorders and Reading Retardation. *Journal of Child Psychology and Psychiatry, 31*(7), 1027-1050. doi:10.1111/j.1469-7610.1990.tb00844.x

Bornstein, M. H. and Haynes, O. M. (1998), Vocabulary Competence in Early Childhood: Measurement, Latent Construct, and Predictive Validity. Child Development, 69: 654–671. doi:10.1111/j.1467-8624.1998.tb06235.x

Campbell, T. F., Dollaghan, C. A., Rockette, H. E., Paradise, J. L., Feldman, H. M., Shriberg, L. D., . . . Kurs-Lasky, M. (2003). Risk Factors for Speech Delay of Unknown Origin in 3-Year-Old Children. *Child Development, 74*(2), 346-357. doi:10.1111/1467-8624.7402002

Davis, B. L. & MacNeilage, P. F. (1990). Acquisition of Correct Vowel Production, A Quantitative Case Study. *J Speech Hear Res*, 33(1), 16-27. doi: 10.1044/jshr.3301.16.

Feldman, H. M., Dale, P. S., Campbell, T. F., Colborn, D. K., Kurs-Lasky, M., Rockette, H. E., & Paradise, J. L. (2005). Concurrent and Predictive Validity of Parent Reports of Child Language at Ages 2 and 3 Years. *Child Development, 76*(4), 856-868. doi:10.1111/j.1467-8624.2005.00882.x

Feldman, H. M., Dollaghan, C. A., Campbell, T. F., Kurs-Lasky, M., Janosky, J. J., & Paradise, J. L. (2000). Measurement properties of the MacArthur Communicative Development Inventories at ages one and two years. *Child Development, 71,* 310–322. doi:10.1111/1467-8624.00146

Fenson, L., Bates, E., Dale, P., Goodman, J., Reznick, J. S., & Thal, D. (2000). Reply: Measuring Variability in Early Child Language: Don't Shoot the Messenger. *Child Development, 71*(2), 323-328. doi:10.1111/1467-8624.00147

Fenson, L., Dale, P. S., Reznick, J. S., Thal, D., Bates, E., Hartung, J. P., Pethick, S., & Reilly, J. S. (1993). *The MacArthur Communicative Development Inventories: User's guide and technical manual*. San Diego: Singular Publishing Group.

Frank, M. C., Braginsky, M., Yurovsky, D., & Marchman, V. A. (2016). Wordbank: An open repository for developmental vocabulary data. Journal of Child Language. doi: 10.1017/S0305000916000209.

Friend M, Diaz K. Relation between parent report and child performance on vocabulary comprehension. Paper presented at the Conference on Early Lexicon Acquisition: Normal and pathological development; Lyon, France. 2001, December.

Friend, M., & Keplinger, M. (2003). An infant-based assessment of early lexicon acquisition. *Behavior Research Methods, Instruments, & Computers, 35*(2), 302-309. doi:10.3758/bf03202556

Friend, M., Schmitt, S. A., & Simpson, A. M. (2012). Evaluating the predictive validity of the Computerized Comprehension Task: Comprehension predicts production. *Developmental Psychology, 48*(1), 136-148. doi:10.1037/a0025511

Golinkoff, R. M., Hirsh-Pasek, K., Cauley, K. M., & Gordon, L. (1987). The eyes have it: lexical and syntactic comprehension in a new paradigm. *Journal of Child Language, 14*(01), 23. doi:10.1017/s030500090001271x

Hale, M., & Reiss, C. (1998). Formal and Empirical Arguments concerning Phonological Acquisition. *Linguistic Inquiry, 29*(4), 656-683. doi:10.1162/002438998553914

Hart, B. & Risley, T. (1995). *Meaningful differences in the everyday experience of young American children.* Baltimore: Paul H. Brookes Publishing.(2004 printing).

Hoff, E. (2003). The Specificity of Environmental Influence: Socioeconomic Status Affects Early Vocabulary Development Via Maternal Speech. *Child Development, 74*(5), 1368-1378. doi:10.1111/1467-8624.00612

Jyoti, D., Frongillo, E., Jones, S. (2005). Food insecurity affects school children's academic performance, weight gain, and social skills. The Journal of Nutrition, 135 (12), 2831-2839.

Kuhl, P. K. (2009). Linking infant speech perception to language acquisition: Phonetic learning predicts language growth. In J. Colombo, P. McCardle, & L. Freund (Eds.), *Infant pathways to language: Methods, models, and research disorders* (pp. 213–244). New York, NY: Psychology Press.

Larrivee, L. S., & Catts, H. W. (1999). Early reading achievement in children with expressive phonological disorders. American Journal of Speech-Language Pathology, 8, 118–128.

Legacy, J., Poulin-Dubois, D., Zesiger, P., Friend, M. (2014, July). *Using the CCT to assess early vocabulary development in monolingual and bilingual infants.* Poster session presented at the 13th International Congress for the Study of Child Language: Amsterdam.

Lewis, B. A., Avrich, A. A., Freebairn, L. A., Hansen, A. J., Sucheston, L. E., Kuo, I., . . . Stein, C. M. (2011). Literacy Outcomes of Children With Early Childhood Speech Sound Disorders: Impact of Endophenotypes. *Journal of Speech, Language, and Hearing Research, 54*(6), 1628-1643. doi:10.1044/1092-4388(2011/10-0124)

Lewis, B. A., Freebairn, L. A., & Taylor, H. (2000). Academic outcomes in children with histories of speech sound disorders. *Journal of Communication Disorders, 33*(1), 11-30. doi:10.1016/s0021-9924(99)00023-4

Lewis, B. A., Shriberg, L. D., Freebairn, L. A., Hansen, A. J., Stein, C. M., Taylor, H. G., & Iyengar, S. K. (2006). The Genetic Bases of Speech Sound Disorders: Evidence From Spoken and Written Language. *J Speech Lang Hear Res Journal of Speech Language and Hearing Research, 49*(6), 1294. doi:10.1044/1092-4388(2006/093)

Marchman, V. A., & Fernald, A. (2008). Speed of word recognition and vocabulary knowledge in infancy predict cognitive and language outcomes in later childhood. *Developmental Science, 0*(0). doi:10.1111/j.1467-7687.2007.00671.x

Majorano, M., Vihman, M. M., & Depaolis, R. A. (2013). The Relationship Between Infants' Production Experience and Their Processing of Speech. *Language Learning and Development, 10*(2), 179-204. doi:10.1080/15475441.2013.829740

Mcgowan, J. E., Alderdice, F. A., Holmes, V. A., & Johnston, L. (2011). Early Childhood Development of Late-Preterm Infants: A Systematic Review. *Pediatrics, 127*(6), 1111-1124. doi:10.1542/peds.2010-2257

Mullen, E. M. (1995). *Mullen Scales of Early Learning* (AGS ed.). Circle Pines, MN: American Guidance Service Inc.

Nelson, H. D., Nygren, P., Walker, M., & Panocha, R. (2006). Screening for Speech and Language Delay in Preschool Children: Systematic Evidence Review for the US Preventive Services Task Force. *Pediatrics, 117*(2). doi:10.1542/peds.2005-1467

Pennington, B. F., & Bishop, D. V. (2009). Relations Among Speech, Language, and Reading Disorders. *Annual Review of Psychology, 60*(1), 283-306. doi:10.1146/annurev.psych.60.110707.163548

Raitano N. A., Pennington B. F., Tunick R. A., Boada R., Shriberg L. D. Pre-literacy skills of subgroups of children with speech sound disorders. Journal of Child Psychology and Psychiatry. 2004;45:821–835.

Rvachew, S., & Grawburg, M. (2006). Correlates of Phonological Awareness in Preschoolers With Speech Sound Disorders. *Journal of Speech, Language, and Hearing Research, 49*(1), 74-87. doi:10.1044/1092-4388(2006/006)

Rvachew, S., Ohberg, A., Grawburg, M., & Heyding, J. (2003). Phonological Awareness and Phonemic Perception in 4-Year-Old Children With Delayed Expressive Phonology Skills. *American Journal of Speech-Language Pathology, 12*(4), 463. doi:10.1044/1058-0360(2003/092)

Shriberg, L. D., Tomblin, J. B., & Mcsweeny, J. L. (1999). Prevalence of Speech Delay in 6-Year-Old Children and Comorbidity With Language Impairment. *Journal of Speech Language and Hearing Research, 42*(6), 1461. doi:10.1044/jslhr.4206.1461

Sansavini, A., Guarini, A., Savini, S., Broccoli, S., Justice, L., Alessandroni, R., & Faldella, G. (2011). Longitudinal trajectories of gestural and linguistic abilities in very preterm infants in the second year of life. *Neuropsychologia, 49*(13), 3677-3688. doi:10.1016/j.neuropsychologia.2011.09.023

Snyder, L., Bates, E., & Bretherton, I. (1981). Content and context in early lexical development. Journal of ChiM Language, 8, 565-582.

Tsao, F., Liu, H., & Kuhl, P. K. (2004). Speech Perception in Infancy Predicts Language Development in the Second Year of Life: A Longitudinal Study. *Child Development, 75*(4), 1067-1084. doi:10.1111/j.1467-8624.2004.00726.x

APPENDIX

CCT Elicitation Questions:

Nouns: Where is the ________?
Verbs: Who is __________?
Adjectives: Which one is ______?