The Temporal Relationship between Speech and Manual Communicative Gesture in Children with Specific Language Impairment

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Abstract

This study examined the relationship between word frequency and timing of communicative gestures in children with specific language impairment (SLI) and typically-developing (TD) children. Nine children with SLI and twelve age-matched TD children produced a narrative after watching an animated cartoon. Redundant gesture-speech pairs were identified and coded for temporal alignment between gesture and speech onset and gesture duration. Word frequency for the co-occurring words was determined using the SUBTLEXus database. No significant group differences were found for temporal alignment or gesture duration. However, word frequency was associated with temporal alignment and gesture duration in TD children, but not in children with SLI. This finding suggests that the role communicative gestures play in lexical access is different in children with SLI relative to TD children.

Key words: specific language impairment, temporal alignment, gesture duration, word frequency, children ages 6 to 10 years

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Introduction

This study investigated the temporal alignment of gestures and speech in children with specific language impairment (SLI) and typically-developing age-matched children (TD). SLI is a developmental language disorder, in which children exhibit deficits in language development in the absence of intellectual disabilities, frank neurological damage, social or emotional disorders, hearing loss and frank oral motor dysfunction (Leonard, 2014). The language impairment commonly observed in SLI is primarily in grammatical abilities. Specifically, individuals with SLI show poor application and comprehension of derivational and inflectional verb morphology, and poor production and comprehension of complex sentences consisting of relative clauses and long-distance dependencies (Rice & Wexler, 1996; Ullman & Gopnik, 1999). Although the majority of past research has focused on grammatical impairments in children with SLI, impairments in lexical and semantic areas of language have been observed in children with SLI, as well (Mainela-Arnold, Evans & Coady, 2010; Sheng & McGregor, 2010).

A handful of studies have explored manual gestures accompanying speech in children with SLI. Researchers have hypothesized that, because of their verbal deficits and relative strengths in non-verbal areas, children with SLI may rely more on gesture than TD children when communicating (Evans, Alibali, & McNeil, 2001; Iverson & Braddock, 2011; Blake, Myszczyszyn, Jokel, & Bebiroglu, 2008).

Relationship between speech and co-occurring manual gestures

Gestures typically convey meaning related to the content expressed in spoken language. As such, they may strengthen a recipient's comprehension by providing information that is redundant with the speaker's verbal message. They may also function as an organizational tool for the speaker, assisting with the conceptual planning of speech or facilitating lexical access (Alibali, Kita & Young, 2000; McNeill, 1992; Rauscher et al., 1996). An example of such a gesture is a circular motion produced with a hand, which might co-occur with the word "spin" when a speaker talks about someone spinning on an exercise bar (Alibali, Evans, Hostetter, Ryan & Mainela-Arnold, 2009). The information expressed in gesture is redundant with the information expressed in speech.

Sometimes, however, in addition to supplementing speech with a semantically redundant gesture, gestures relay new content that is not present in speech. A speaker who talks about someone "going faster" and produces a spinning hand motion with the word "faster" is conveying content about the type of movement in the gesture that adds to the content conveyed in speech. This gesture is non-redundant with the information expressed in speech. In order to examine speech-gesture redundancy, investigators have developed gesture lexicons for coding the meanings of particular gestures in particular tasks, enabling them to identify redundant and non-redundant gesture-speech combinations (Alibali, Evans, Hostetter, Ryan & Mainela-Arnold, 2009).

Some researchers have hypothesized that, because of their verbal deficits, children with SLI would gesture more and would produce more non-redundant gestures, or gestures that convey information that is not present in speech. However, research findings have been inconsistent. Some studies have reported that, in comparison to their peers, children with SLI produce representational gestures at a higher rate (Iverson & Braddock, 2011; Mainela-Arnold, Alibali, Hostetter & Evans, 2014). However, one study reported that children with SLI did not differ from peers in the frequency of iconic gestures, beat (rhythmic) gestures or points (Blake, Myszczyszyn, Jokel & Bebiroglu, 2008).

Children with SLI have also been reported to express information in non-redundant gestures more often than typically-developing children (Evans et al., 2001; Iverson & Braddock, 2011). However, Mainela-Arnold, Alibali, Hostetter and Evans (2014) found that, although participants with SLI produced more non-redundant gestures than TD participants in a narrative task, they also produced more redundant gestures. Thus, the overall likelihood that a gesture was non-redundant did not differ in the two groups.

These mixed results suggest that the hypothesis that children with SLI rely more on gesture when communicating needs to be refined. One factor that may affect gesture use in children with SLI is deficits in manual praxis and coordination.

Studies examining praxis in SLI have shown that children with SLI have difficulty executing familiar actions on demand (e.g., imitating combing your hair with a brush) in comparison to imitating sequences of unfamiliar actions (e.g. Hill, 1998). A qualitative analysis of the familiar actions produced by children with SLI revealed that their difficulties executing actions were similar to those of TD children, but greater in frequency (Hill et al., 1998). However, despite the increased number of errors, the actions produced by children with SLI still resembled the intended action. Based on these findings, Hill et al., (1998) suggested that difficulties with manual praxis might not lie in conceptualizing the action, but rather in executing the sequence of movements of the action.

In addition to difficulties with manual praxis, children with SLI exhibit poor motor coordination (Vukovic, Vukovic & Stojanovik, 2010; Zelaznik & Goffman, 2010). Studies have shown that children with SLI show poor upper limb coordination and bilateral coordination (Zelaznik & Goffman, 2010) and a delayed onset of the development of arm and leg coordination in comparison to TD children (Vukovic, Vukovic & Stojanovik, 2010). The observed motor coordination difficulties in SLI, similar to the difficulties with manual praxis, may be the result of poor sequential organization of the separate elements of a coordinated action. This suggests that gesture duration and temporal alignment of speech and co-occurring gestures in children with SLI might differ from TD children.

Iverson and Braddock (2011) found that children who had lower expressive language abilities tended to gesture more, but also performed more poorly on standardized measures of fine motor functioning, than children with higher expressive language abilities. In their regression analysis, the variance in language abilities that was accounted for by gesture use was reduced when measurements of fine motor abilities were entered into the regression model, suggesting that children's ability to use gestures to supplement their spoken language is constrained by their fine motor abilities.

In the current study, we investigated temporal alignment between speech and gesture in children with SLI and TD children. Because of the reported motor deficits in

SLI, we expected to find group differences in the temporal alignment of speech and gesture, and in gesture duration.

Temporal relationship between gesture and speech

A few studies have directly examined the temporal alignment of speech and the accompanying gesture. Generally, the temporal measures investigated include *temporal alignment*, the absolute difference between onset times of the word and the associated gesture, and *gesture duration*, the difference between the start and end of the accompanying gesture.

One recent study (de Marchena & Eigsti, 2010) examined the temporal alignment of speech and gestures in adolescents with autism spectrum disorder (ASD) in a story-telling task. Several aspects of temporal alignment were compared between participants with ASD and age-matched controls. There was a significant difference in the temporal alignment of gesture and speech between groups. The time lag between gesture onset and speech onset for the ASD group was approximately 490ms, while for the control group it was only 240ms. In the control group, the stroke phases of the gestures – the portion of the gesture that contains semantic information – occurred as early as 460ms prior to the onset of the related speech and as late as 280ms after speech onset. The stroke phases of the gestures produced by the ASD group, however, occurred as early as 2770ms before and as late as 930ms after the onset of related speech. This group difference in temporal alignment of speech and gesture was statistically significant. The authors concluded that atypical cerebellar development might affect temporal alignment of speech and gesture in ASD. In addition to collecting temporal information about the speech and co-occurring gesture, the quality of children's narratives was rated. Not only was the quality of narratives in the ASD group rated lower than that in the control group, but the asynchrony between speech and gesture was associated with the quality of the narratives, as well.

Temporal alignment of gesture and speech may be affected, not only by motor abilities, but also by linguistic factors. Morrel-Samuels and Krauss (1992) hypothesized that if gesture facilitates lexical access, then the difference between the onsets of gesture and corresponding words would be predicted by the accessibility of the lexical items, defined by word familiarity ratings. Participants were asked to produce a narrative description of a series of photographs. The results showed that, in their sample of undergraduate students, gestures always preceded the lexical affiliate, but the range of gesture-speech asynchrony varied considerably (0 – 3800ms). Gesture duration was highly positively correlated with gesture-speech asynchrony, and both gesture-speech asynchrony and gesture duration were predicted by lexical accessibility. These findings indicate that the temporal alignment of gestures with speech is affected by lexical factors. Based on these findings, Morrel-Samuels and Krauss (1992) argued that gestures acted as a conceptual or lexical prime for verbal expression.

Lexical learning and processing in children with SLI differs from age expectations. Children with SLI exhibit compromised picture naming (e.g. Lahey & Edwards, 1999) and spoken word recognition (e.g. Mainela-Arnold, Evans, & Coady, 2008). According to a meta-analysis of word learning studies, children with SLI also exhibit difficulties in learning labels for novel referents (Kan & Windsor, 2010). Studies focusing on word definitions, drawings of word meanings, word associations and novel word learning are indicative of reduced understanding of meanings of words, reduced encoding of semantic features of words, and deficits in semantic organization (Alt & Plante, 2006; Mainela-Arnold, Evans, & Coady, 2010; McGregor, Newman, Reilly & Capone, 2002; Sheng & McGregor, 2010). Because of the reported lexical deficits in SLI, it is of interest to examine the relation between word frequency and gesture timing in this population. If gesture facilitates lexical access, we would expect that when children with SLI produce low frequency words, their gestures should be especially long in duration and should occur far in time from the corresponding word.

Current Study

The primary objective of this study was to compare the temporal alignment of speech and the associated manual communicative gestures between children with SLI and TD children. Temporal alignment was defined as the absolute difference in time between the start of speech and the start of the co-occurring gesture. We also measured gesture duration, defined as the difference in time between the end and the start of a gesture. Based on reports of difficulties with manual praxis and coordination in SLI (Hill, 2001), we predicted that the SLI group would produce gesture-speech pairs that were less temporally aligned and would produce gestures of greater duration, in comparison to a TD group.

The second primary objective of this study was to evaluate the relation between word frequency and temporal alignment and duration in both the SLI and TD groups. Previous research suggests that the temporal alignment of gestures and speech is related to the accessibility of the words occurring with the gesture, as measured by word familiarity ratings (Morrel-Samuels & Krauss, 1992). Based on reports of lexical deficits in SLI, we predicted that the relation between word frequency and temporal alignment and duration would be stronger in the SLI group than in the TD group.

Methods

Participants

Twenty-nine children (ages 6;0 – 10;0), including 12 SLI and 17 age-matched TD controls, participated in this study.[1] All of the participants met the following criteria: (1) monolingual English home environment, (2) no frank neurological damage, (3) passed a hearing screen at 500, 1000, 2000, and 4000 Hz and 20 dB HL, (4) scored at or above 85 on either the Columbia Mental Maturity Scale (Burgemeister, Hollander Blum, & Lorge, 1972), the Leiter International Performance Scale (Roid & Miller, 1997) or the test of Nonverbal Intelligence (Brown, Sherbenou & Johnsen, 1990) as a measure of nonverbal intelligence, (4) no oral motor or speech dysfunction, and (5) no emotional or social disorders.

Children's language abilities were assessed using the Clinical Evaluation of Language Fundamentals – Revised (CELF-R; Semel, Wiig, & Secord, 1987). To be placed in the SLI group, children were required to score at least one standard deviation below the

[1] The original dataset consisted of 15 children with SLI and 18 children with typical development (e.g. Mainela-Arnold et al., 2014). However, video files of four participants, 3 children with SLI and 1 child with typical development, were corrupted, reducing our sample to 12 children with SLI and 17 children with typical development.

mean on either the CELF-R Expressive or Receptive Language Index or both, and they must have been receiving services for language-related difficulties. To be placed in the TD group, participants were required to score within the normal range on the Expressive Language Index and the Oral Directions receptive subtest of the CELF-R (see Table 1), and they must not have received or have been receiving services for language-related difficulties.

To reliably measure the effects of word frequency on temporal alignment of gesture and speech, and gesture duration, only redundant gesture-speech pairs were analyzed (as in Morrel-Samuels & Krauss, 1992). We eliminated non-redundant gesture-speech pairs from our analysis, because the information children express in gesture in such pairs might not be part of their vocabulary, and this could affect the duration of the gesture and/or the alignment of gesture and speech in unknown ways. This ensured that the information each child expressed in gesture was also part of the child's vocabulary.

After excluding participants who produced only non-redundant gesture-speech pairs (n = 1 SLI; n = 2 TD) and participants who did not produce any gestures (n = 2 SLI; n = 3 TD), the sample was reduced to 21 children, including 9 children with SLI and 12 age-matched TD controls (ages 6;2 – 10;0).

The children in this study also participated in a series of other experimental tasks investigating gesture (reported in Mainela-Arnold et al., 2006; Mainela-Arnold et al., 2011). The current analysis is a secondary analysis of a subset of data presented in previous manuscripts (Alibali et al., 2009; Mainela-Arnold et al., 2014).

Materials

A narrative task was used to elicit speech and gestures. The stimulus was a wordless cartoon video from *Die Sendung mit der Maus*. The sequence of events that took place in the cartoon video is as follows: A mouse walks towards a high bar and jumps up to grab the bar. The mouse swings on the bar and eventually begins to spin around it. Soon after, an elephant enters the scene and watches the mouse on the bar. Once the mouse jumps down from the bar, the elephant walks towards the bar and attempts to grab hold of it. The elephant finally grabs hold of the bar with his trunk and bends it. Infuriated, the mouse gestures for the elephant to step back as he attempts to repair the bent bar. The mouse fails to fix the bent bar and gives up. Then, a leprechaun wearing a top hat enters the scene and walks underneath the bar. His top hat touches the bar and magically repairs it. The leprechaun leaves, the elephant laughs and the mouse pouts in embarrassment.

Procedure

Each child was accompanied by two experimenters. The first experimenter remained with the child throughout the experiment, presented the cartoon video that the child had to later narrate, and asked questions that encouraged the child to explain certain scenes and characters in more detail. The second experimenter acted as a confederate, and was not present in the room while the child watched the video. It was expected that by leading the child to believe that the second experimenter had never seen the cartoon, the child would provide a more thorough description of the cartoon and would produce more speech-gesture pairs.

After watching the video, the child narrated the story to the confederate. Once the child had finished telling the story, the first experimenter asked a series of questions that prompted the child to elaborate on the narrative. These were: (1) Tell a little bit more about what happened when the mouse was first hanging on the bar, (2) Tell a little bit more about when the mouse's friend tried to hang on the bar, (3) Tell a little bit more about what the mouse did to try to fix the bar, and (4) Tell a little bit more about the man with the hat.

Coding

For the purposes of this study, we identified representational gestures, defined as movements that express semantic information. These gestures were assigned one of thirteen specific meanings from the lexicon developed by Alibali et al. (2009). For example, a gesture that included a back and forth motion using hands or legs was assigned the meaning SWING or a gesture that included an alternate stomping motion using feet or hands was assigned the meaning WALK. Only gestures that were assigned a meaning from the lexicon were used in the analyses to follow.

For each gesture, we also identified the co-occurring words in the child's accompanying speech. We classified each gesture-speech combination as either redundant (see example 1) or non-redundant (see example 2). For the purposes of this study, only redundant gesture-speech combinations were included in statistical analyses.

(1) [SPIN]

The mouse was spinning on the bar

(2) [HAT]

The magic man fixed the bar

Once the gestures and the words expressing redundant content were identified, the start and end times of the gestures and co-occurring words were recorded. The onset of the first phoneme of the co-occurring word was coded as the speech start time, while the offset of the last phoneme of the co-occurring word was coded as the speech end time. For gestures, the onset and offset of the stroke phase were coded as the start and end times respectively. If a child produced a sequence of gestures without returning to a rest position (retraction phase), each stroke phase was recorded as a separate gesture.

Children's narratives were video recorded using a digital high 8 camera and converted into .wav and .mp4 files to code gesture and speech using the multimedia annotator ELAN. This software enables the video recording to be examined frame by frame and the time linked audio recording to be visualized. This ensured maximal accuracy in identifying the start and end times of both gestures and the redundant co-occurring words, and the absolute time difference between the start of the gesture and the redundant co-occurring word.

Word frequency was determined for the co-occurring words in the gesture-speech pairs using the SUBTLEXus database (Brysbaert & New, 2009). Of several measures provided by the database, the log10 frequency measure was used and examined as a continuous variable. The logarithm transformation was preferred because it normalized the data.

Reliability of coding. Two coders independently coded the start and end times for gestures and associated words. Absolute agreement between start and end times was measured using a two-way mixed model intra-class correlation (ICC), a commonly-used measure of inter-rater reliability for ratio variables (Hallgren, 2012). For start and end times of associated words, a single measures ICC =1.00 ($p < 0.01$, 95% confidence interval of .999 to 1.00) was achieved for 20% of gesture-speech pairs. For start and end times of gestures, a single measures ICC = .999 ($p < 0.01$, 95% confidence interval of .998 to .999) was achieved for 20% of gesture-speech pairs.

Results

We sought to compare the following two temporal measures between the SLI and TD groups: (1) the absolute time difference between the beginning of the gesture and the redundant co-occurring word (temporal alignment) and (2) gesture duration (duration) (see Table 2). However, before addressing our primary hypotheses regarding temporal alignment and gesture duration, we noted that there were significant group differences in nonverbal IQ (see Table 1). Thus, we first examined whether nonverbal IQ was associated with these outcome measures. To do so, we evaluated two mixed-effects models: (1) a model that included participant and gesture type (i.e., the meaning category to which each gesture was assigned; see the Coding section) as random factors to account for the variability associated with each participant and with different gesture meanings, and (2) a model that included participant and gesture type as random factors, and nonverbal IQ as a fixed factor. These models were then compared using an ANOVA test of log likelihood values. The chi-square value from the ANOVA test was used to establish whether the model that included nonverbal IQ as a factor fit the data better than the model without nonverbal IQ. For both temporal alignment and gesture duration, this was not the case, X^2 $(1, N = 21) = 0.32$, $p = 0.57$ and X^2 $(1, N = 21) = 0.20$, $p = 0.66$, respectively. Thus, nonverbal IQ did not significantly affect the temporal alignment or gesture duration of gesture-speech pairs.

We next examined whether language status affected temporal alignment of gesture-speech pairs. Given that at least some children with SLI are reported to present with motor deficits, we predicted that the temporal alignment of gesture-speech pairs would differ between children with SLI and TD children. To test our hypothesis, we compared the second model (i.e., the one that included participant and gesture type as random factors, and nonverbal IQ as a fixed factor) with (3) a model that included participant and gesture type as random factors, and nonverbal IQ and participant group (SLI or TD) as fixed factors. We found that the model that included participant group as a factor did not fit the data better than the model without participant group, X^2 $(1, N = 21) = 0.66$, $p = 0.42$. Thus, participant group did not account for variation in the temporal alignment of gesture-speech pairs.

We next asked whether gesture duration differed for children with SLI and TD children. Using the same approach as the previous analysis, we again found that the model with participant group did not fit the data better than the model without participant group,

X^2 (1, N = 21) = 0.0031, p = 0.96. In short, contrary to our predictions, the temporal alignment and duration of gesture-speech pairs did not differ significantly in the SLI and TD groups (see Figure 1).

Our second set of analyses examined the effects of word frequency on temporal alignment and gesture duration in the SLI and TD groups. We predicted that temporal alignment of gesture-speech pairs and gesture duration would be affected by word frequency in both groups. However, given their reported difficulties with lexical access, we expected to see a stronger effect of word frequency on temporal alignment and gesture duration in the SLI group. Thus, we predicted a significant interaction of participant group and word frequency for each outcome measure.

To evaluate word frequency effects on temporal alignment and gesture duration, we compared: (4) a model that included participant and gesture type as random factors and nonverbal IQ and participant group as fixed factors to (5) a model that included participant and gesture type as random factors and nonverbal IQ, participant group and word frequency as fixed factors. Then, to address the effect of word frequency across participant groups on these temporal measures, we compared the fifth model to (6) a model that included participant and gesture type as random factors and nonverbal IQ and the participant group by word frequency interaction as fixed factors.

We first examined predictors of temporal alignment. Based on past work, we expected that the asynchrony between gesture onset and speech onset would be greater for less frequent words; thus we expected a negative relationship in both groups. The comparison between the fourth and fifth models showed that, as expected, word frequency was a significant predictor of temporal alignment, $X^2(1, N = 21) = 6.29$, $p = 0.012$ and the comparison between the fifth and sixth models showed that the participant group by word frequency interaction was a significant predictor of temporal alignment, $X^2(1, N = 21) = 5.17$, $p = 0.023$. A closer examination of this effect revealed that as word frequency increased, temporal alignment of gesture and speech decreased in the TD group. In the SLI group however, this effect was not observed (see Figure 2).

We next considered gesture duration. The first comparison showed that, as expected, word frequency was a significant predictor of gesture duration, $X^2(1, N = 21) = 4.20$, $p = 0.040$, and the comparison between the fifth and sixth models showed that the participant group by word frequency interaction was also significant, $X^2(1, N =21) = 6.82$, $p = 0.0090$. Examining this interaction further revealed that as word frequency increased, gesture duration decreased in the TD group, while word frequency was not related to duration in the SLI group (see Figure 3).

Therefore, the effect of word frequency on temporal alignment and gesture duration was not stronger in the SLI group than the TD group. In fact, the opposite was found: the effects of word frequency present in the TD group were not found for the SLI group.

Discussion

The purpose of this study was to examine whether the temporal alignment of gesture and speech and gesture duration differed between children with SLI and TD children, and to examine whether associations with word frequency were similar between groups. To address these questions, we examined (1) the temporal alignment of speech and gesture and gesture duration and, (2) the effects of word frequency on these temporal measures in children in children with SLI and TD children. We hypothesized that (1) the gesture-speech pairs produced by children with SLI would be less temporally aligned and greater in duration than the gesture-speech pairs produced by TD children, and (2) word frequency effects on temporal alignment and duration would be observed in both children with SLI and TD children, but they would be more pronounced in children with SLI. Contrary to our predictions, we found that that temporal alignment and duration of gesture-speech pairs produced by children with SLI and TD children did not differ significantly. However, the effects of word frequency on temporal alignment and duration differed between the SLI and TD groups. Specifically, as word frequency increased, temporal alignment and duration decreased in the TD group. However, word frequency was not related to temporal alignment or duration in the SLI group. These findings were evident, even after controlling for group differences in non-verbal IQ.

The finding of no significant differences in temporal alignment and duration may suggest that, despite reports of subtle deficits in the production of representational gestures in children with SLI (Hill, 1998; Hill et al., 1998), the temporal alignment and duration of communicative representational gestures is not significantly affected by the reported motor deficits in SLI.

An important factor to consider is that children with SLI may not show deficits in all aspects of motor skill, such as timing and coordination. This suggestion is supported not only by evidence from the current study, but also by evidence from two additional studies that have in some form, tested motor timing and coordination in children with SLI (Hsu & Bishop, 2014; Zelaznik & Goffman, 2010). Zelaznik and Goffman (2010) compared motor skill and timing in children with and without SLI using a standardized measure of motor ability, and several manual timing tasks including finger and hand tapping and circle drawing. Their results confirmed that children with SLI exhibit fine and gross motor difficulties, but revealed that their rhythmic timing was comparable to that of TD children (Zelaznik & Goffman, 2010). Hsu and Bishop (2014) examined the pursuit rotor task, a hand-eye coordination task, in children with SLI and TD children. Their analyses showed that performance on the pursuit rotor task was comparable in children with SLI and TD children. Based on the findings of these two studies and the current study, it appears that the reported motor deficits may not affect temporal alignment and duration of communicative gestures.

The finding that temporal alignment of speech and gesture and gesture duration were affected by word frequency in TD children, but not in children with SLI, suggests that TD children may use gesture to facilitate lexical access, but children with SLI do not. To our knowledge, the present findings are the first to replicate Morrel-Samuels and Krauss's (1992) findings on adults and extend them to TD children, and the first to show that these patterns do not generalize to children with SLI. The increased gesture duration and longer delays between gestures and spoken words for less frequent words in TD children may be a reflection of their using gestures to help activate the less accessible lower frequency words. Children with SLI, in contrast, may not be using gesture to facilitate lexical access. In previous work, we postulated that increased gesture rates in children with SLI may reflect either an attempt to facilitate lexical access or a preference for representing information in a more embodied manner (Mainela-Arnold, Alibali, Hostetter & Evans, 2014). Since the current analysis found no relationship between accessibility of words and gesture duration and temporal alignment in children with SLI, it lends support to the idea that increased gesture rates in children with SLI are due to a preference for representing information in an embodied manner, rather than due to children using gesture to facilitate lexical access.

One limitation of this study was that the sample size of 9 children with SLI and 12 TD children was small. Therefore, the power of the analysis could be low, and small but true effects may have not been detected. However, given the significant findings for word frequency, the analyses are unlikely to be severely underpowered. Moreover, as seen in the figures, there was no hint of a relationship between temporal alignment and word frequency in children with SLI, and the relationship between gesture duration and word frequency was non-significant but in the opposite of the predicted direction.

Conclusions

Our findings indicate that the temporal alignment of gesture-speech pairs and the duration of gestures produced by children with SLI and TD children are similar. These findings suggest that communicative gestures may be unaffected by the motor deficits in SLI, at least in terms of timing. On the other hand, the effects of word frequency on temporal alignment and gesture duration differed between the SLI and TD groups. Specifically, as word frequency increased, temporal alignment and gesture duration decreased in the TD group, while remaining nearly unaffected in the SLI group. Thus, the role communicative gestures play in lexical access may differ for children with SLI and TD children. We suggest that communicative gesturing in children with SLI may reflect a preference to represent information in an embodied rather than an abstract linguistic manner.

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Table 1. Descriptive Statistics for Ages and Standardized Test Scores

	Age in Months	**IQ[a]**	**ELS[b]**	**RLS[c]**	**OD[d]**
SLI					
Mean	97.40	103.60*	72.40*	79.80	6.33*
SD	13.87	8.03	9.50	19.50	2.78
Range	74-116	89-118	62-84	50-107	3-12
TD					
Mean	99.33	120.75*	104.67*	N/A	11.50*
SD	13.89	6.68	10.60	N/A	2.32
Range	76-120	112-136	93-130	N/A	8-15

Note. Standard scores have a mean of 100 and a standard deviation of 15.

[a] Columbia Mental Maturity Scale: Standard Score, Leiter International Performance Scale: Standard Score or Test of Nonverbal Intelligence: Standard Score ; [b]Clinical Evaluation of Language Fundamentals – Revised: Expressive Language Score; [c]Clinical Evaluation of Language Fundamentals – Revised: Receptive Language Score; [d]Clinical Evaluation of Language Fundamentals – Revised: Oral Directions Standard Score ; * $p < .05$

Table 2. Descriptive Statistics for Number of Representational Gesture-Speech Pairs, Number of Redundant Gesture-Speech Pairs, Temporal Alignment of Redundant Gesture-Speech Pairs and Duration of Redundant Gestures

	Total Number of Gesture-speech pairs	**Number of Redundant Gesture-speech pairs**	**Temporal Alignment (ms)**	**Gesture Duration (ms)**
SLI				
Mean	10.56	6.56	423.66	1147.75
SD	6.84	3.61	297.62	397.42
Range	5-26	2-12	91-696	397-1797
TD				
Mean	8.92	6.67	396.35	1011.25
SD	6.76	3.61	236.05	649.45
Range	2-19	1-15	101-945	201-2191

Note. * $p < .05$

Figure 1. Gesture duration and temporal alignment of redundant gesture-speech pairs in SLI and TD groups

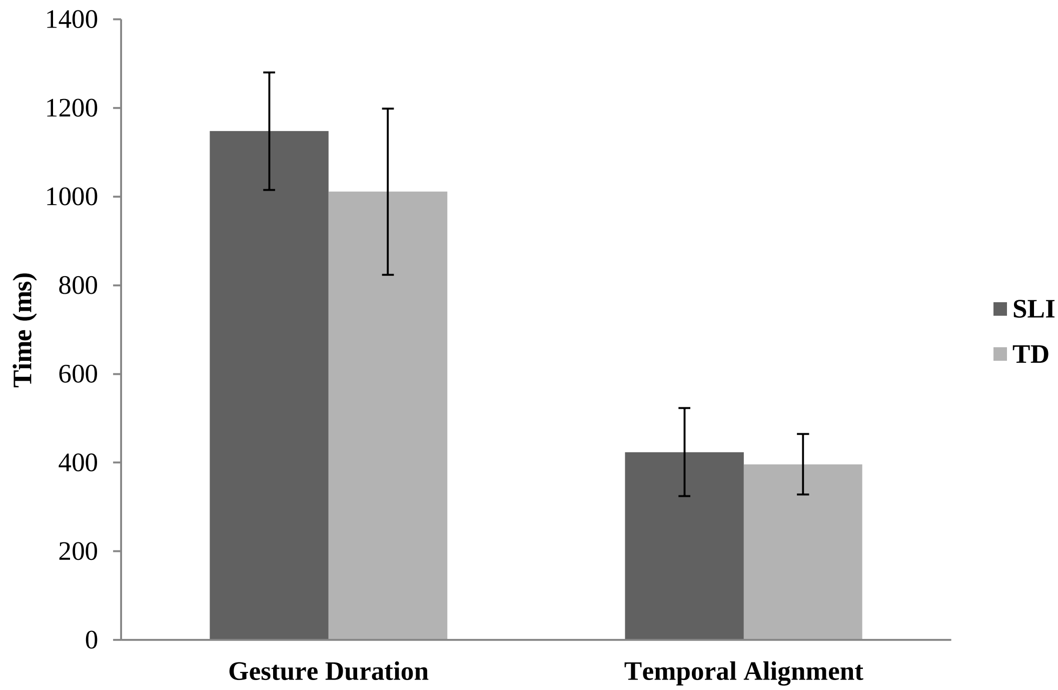
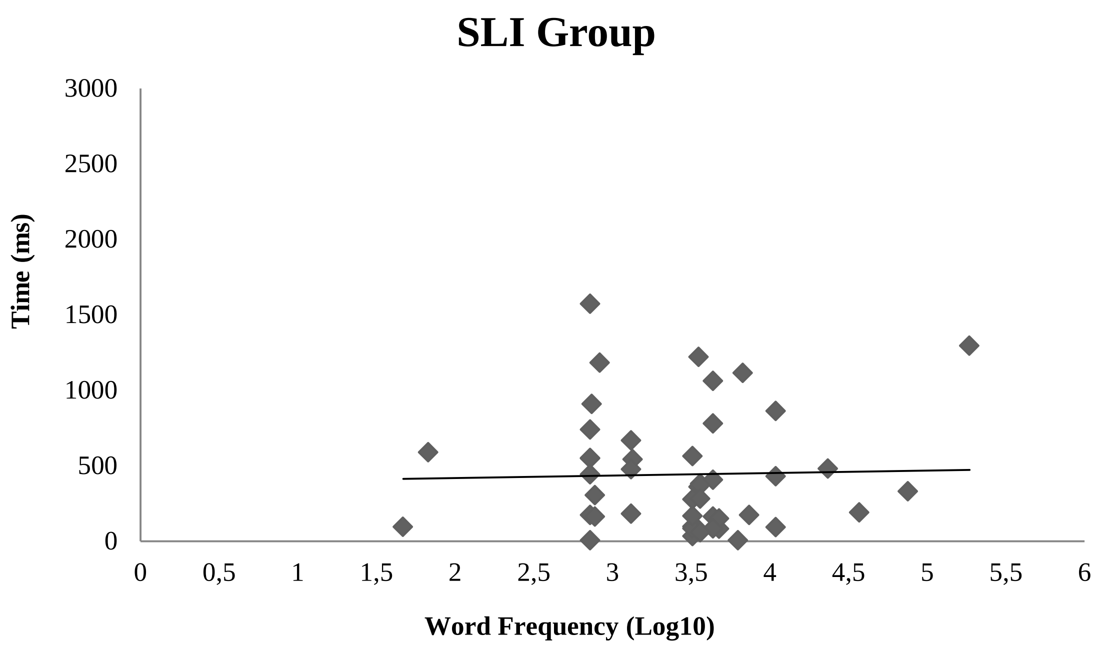


Figure 2. Temporal alignment by word frequency of each gesture-speech pair in the SLI and TD groups



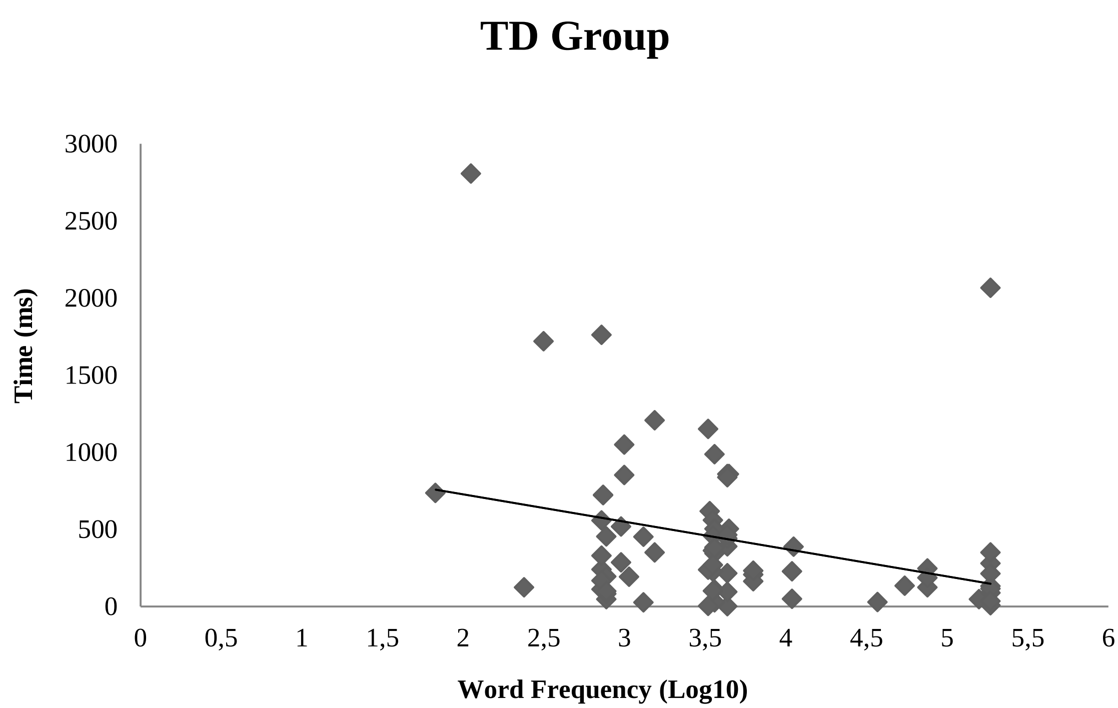


Figure 3. Gesture duration by word frequency for each gesture-speech pair in the SLI and TD groups