Gesture production in language impairment: It's quality not quantity that matters.

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Abstract

Purpose: The aim of this study was to determine whether children with language impairment (LI) use gesture to compensate for their language difficulties.

Method: The present study investigated gesture accuracy and frequency in children with LI (n = 21) across gesture imitation, gesture elicitation, spontaneous narrative and interactive problem solving tasks, relative to typically developing (TD) peers (n = 18) and peers with low language (LL) and educational concerns (n=21).

Results: Children with LI showed weaknesses in gesture accuracy (imitation and gesture elicitation) in comparison to TD peers, but no differences in gesture rate. Children with LL only showed weaknesses in gesture imitation and used significantly more gestures than TD peers during parent-child interaction. Across the whole sample, motor abilities were significantly related to gesture accuracy but not gesture rate. In addition, children with LI produced proportionately more extending gestures, suggesting that they may use gesture to replace words that they are unable to articulate verbally.

Conclusion: The results support the notion that gesture and language form a tightly linked communication system in which gesture deficits are seen alongside difficulties with spoken communication. Furthermore, it is the quality, not quantity of gestures that distinguish children with LI from typical peers.

Key words: Gesture, Language Impairment, Motor skill, Children

Introduction

Gesture commonly accompanies spoken communication at all ages of development. In typically developing (TD) children there is strong evidence that gesture and language are tightly linked, as early gesture use significantly predicts the onset of two word combinations (Iverson & Goldin-Meadow, 2005), children's ability to produce complex sentences, and later vocabulary competence (Rowe & Goldin-Meadow, 2009). Rowe and Goldin-Meadow (2009) reported that individual differences in children's vocabulary level at 52 months could be explained by child gesture use at 14 months. This finding was replicated by Rowe, Özçalışkan, and Goldin-Meadow (2008) who found that child gesture at 14 months was a significant predictor of vocabulary at 42 months, even when child and parent language at 14 months was taken into account. They also found a significant, positive relationship between parent and child gesture at 14 months; however, there was no direct link between parent gesture and children's later vocabulary size. This implies that children's early gesture is important for later language development, while parental gesture may facilitate child gesture in the first instance.

In school aged children, gesture aids learning and problem solving abilities (Alibali & DiRusso, 1999; Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001). For example, Goldin-Meadow et al. (2001) asked participants to solve a maths problem whilst also remembering letters and found that children who were allowed to gesture remembered more of the letters than those who were prohibited from gesturing. This suggests that the act of gesturing may lighten the cognitive load, creating more available space in working memory for complex problem solving tasks. In addition, Goldin-Meadow, Cook, and Mitchell (2009) demonstrated that the accuracy of gesture production influenced task performance; children who were taught to produce an accurate gesture correctly solved more problems than children who were taught only partially correct gestures, or no gestures at all. In addition, those who were taught only partially correct gestures outperformed children who produced no gestures at all. This not only supports the idea that gesture helps children learn new concepts and ideas but also indicates that the more accurately children gesture, the more benefit gesture has for task performance.

Much less is known about the relationship between language and gesture in atypical populations, in particular, populations who display difficulties acquiring spoken language. Language impairment (LI) is generally defined as a language difficulty that occurs in the absence of other developmental concerns, sensory impairments or global developmental delays, and affects 7.58% of children at school entry(Norbury et al., 2016). It is generally assumed that children with LI use non-verbal communication strategies to compensate for their oral language weaknesses. However, gesture is a complex task that requires integrating social, cognitive and motor skills; thus the ability to use gesture effectively in populations in which these precursor skills may be compromised is uncertain. Children with LI have difficulties that extend beyond language and include deficits in attention (Lum, Conti-Ramsden, & Lindell, 2007; Tallal, Dukette, & Curtiss, 1989), procedural memory (Ullman & Pierpont, 2005), working memory (Lum, Conti-Ramsden, Page, & Ullman, 2012; Marton & Schwartz, 2003), perception, (Tallal, Miller, & Fitch, 1993), motor abilities (Iverson & Braddock, 2011; Powell & Bishop, 1992; Webster et al., 2006; Webster, Majnemer, Platt, & Shevell, 2005). All of these skills may be influential in the development of both oral language and gesture development. Exploring gesture abilities in children with LI may further elucidate the relationship between language and gesture to determine whether they form one integrated communication system (McNeill, 1992), or two distinct communication modalities, whereby the function of gesture is to facilitate spoken communication (Hadar, Wenkert-Olenik, Krauss, & Soroker, 1998). For example, if language and gesture form an integrated communication system, children with spoken language deficits may also display difficulties with gesture production. However, if gesture and speech form two separate communication systems, it may be possible that gesture remains intact and children with LI recruit gesture to compensate for their language deficits. The literature concerning gesture use in LI has provided conflicting findings and there is some debate as to how frequently, for what purpose, and how accurately children with LI produce gestures.

Do children with LI gesture more frequently than TD peers?

Children with LI are thought to have a typical drive to communicate (Bishop, 2000), suggesting they may in fact use gesture more frequently than TD peers to enhance communication. Iverson and Braddock (2011) reported that children with LI gestured at a higher rate than TD peers, despite saying fewer utterances per minute, producing fewer different words and having a shorter mean length of utterance. They concluded that children with LI use gesture to compensate for language deficits. Similarly, Mainela-Arnold, Alibali, Hostetter, & Evans (2014) found that during a story re-telling task, children with LI gestured more frequently than TD peers. Consistent with this Lavelli, Barachetti, and Florit (2015) reported children with LI gesture more frequently than age matched TD peers, but at a similar rate to language matched children. However, a handful of studies have reported that children with LI do not gesture any more frequently than TD children (Blake, Myszczyszyn, Jokel, & Bebiroglu, 2008; Evans, Alibali, & McNeil, 2001). Blake et al. (2008) asked children with LI, age-matched TD peers and a language-ability matched younger TD comparison group, to complete a narrative recall task and a classroom description task. No differences were observed between children with LI and either the age-matched or language-matched comparison groups with regard to gesture rate, raising questions about the ability of children with LI to use gesture to compensate for language deficits. However, differences in diagnostic criteria may contribute to these conflicting findings. Nevertheless, while it is unclear whether children with LI use gesture more frequently or at a similar rate to TD peers, there is no direct evidence that children with LI use gesture less frequently. It is therefore prudent to ask whether gesture enhances their communicative efforts.

Are there qualitative differences in the gestures produced by children with LI, relative to TD peers?

Children with LI may use gesture to enhance their communication in at least two ways. First, they may use gesture to reinforce a verbal message that is unclear. In this case, we might expect to see more ‘redundant’ gestures, in which gestures match, and reinforce, the linguistic content of the verbal utterance. Second, gestures may serve to ‘extend’ utterance length by realising concepts the child cannot articulate (Rowe, 2012). A critical question is whether children with LI use a higher proportion of ‘extending’ gestures, or whether their language deficits limit production in any modality. Again there are conflicting findings within the literature regarding how children with LI integrate gesture and speech.

On the one hand, Mainela-Arnold et al. (2014) found no differences between children with LI and TD children in the number of redundant or extending gestures they produced during narrative monologue. This suggests children with LI were predominantly using gesture to reinforce the spoken utterance rather than to express additional information. On the other hand, Evans et al. (2001) found that children with LI were more likely to express unique information through gesture, whereas TD children were more likely to use redundant gestures to express the same concepts in both speech and gesture. A critical difference between studies was the choice of task; Mainela-Arnold et al. (2014) asked children to narrate a wordless cartoon, while Evans et al. (2001) employed a Piagetian conservation task. The narrative task employed by Mainela-Arnold et al. (2014) is arguably conceptually easier for children to complete than the conservation task, as they have pictures available to scaffold their language. As such, the narrative task may not have placed sufficiently high cognitive demands on the children, reducing their need to use gesture to aid their communication. However, other studies of gesture have used similar narrative tasks and have reported that children with LI produce more extending gestures than their TD peers (Blake et al., 2008; Iverson & Braddock, 2011). Mainela-Arnold et al. (2014) and Blake et al. (2008) both used narrative recall tasks, but the Mainela-Arnold et al. (2014) stimuli were non-verbal, only lasted for 90 seconds and children watched this cartoon twice. In contrast, Blake et al. (2008), used a longer cartoon which had a verbal element and was only shown once, increasing working memory demands. Therefore, it is possible that qualitative differences in gesture use by children with LI may only arise when the cognitive and linguistic demands of the task are challenging.

Elicited gesture tasks may again yield different results to studies investigating spontaneous use of gesture. Botting, Riches, Gaynor and Morgan (2010) reported that gesture accuracy is robust in the face of language impairment, at least in school-aged children with LI. In this study, children were presented with pictures of actions, objects, and concepts and asked to tell the researcher what the picture was by only using their hands. Botting et al. (2010) rated gesture accuracy on a scale of 1-5 according to how closely related it was to the target picture and found that the LI group did not differ significantly from a group of age-matched TD peers. In contrast, Hill (1998) reported that children with LI produced less accurate gestures than age-matched TD peers, when asked to either imitate a gesture or produce a gesture in response to a verbal command (e.g. “show me brushing your teeth”). Hill reported that children with LI made errors similar to children with Developmental Co-ordination Disorder (DCD) and a younger TD comparison group. This was true even for children with LI who had motor abilities within the normal range, indicating that their difficulties were not solely due to co-occurring motor impairment. The disparity between these studies could be due to word stimuli, children in Hill (1998), were asked to produce everyday actions, whereas in Botting et al (2010), they varied from actions such as playing tennis, to more abstract words such as wind. However, Wray, Norbury and Alcock (2015), used the same task as Botting et al. (2010) and found that children with LI demonstrated poorer performance during an elicited gesture production task relative to age-matched peers, despite the fact that these same children did not differ from peers on a meaningless gesture imitation task. This suggests that children with LI have difficulties generating gestures even when their motor abilities are sufficient. One explanation for the disparity between studies may be the age of participants. Hill’s (1998) study had a large age range of 5 to 13 years, while children in the Evans et al. (2001) study were aged 7 to 9 years, and Iverson and Braddock’s

(2011) study examined pre-school children aged 2 to 6 years. As gesture use develops and changes throughout childhood (Capirci et al., 1996, Masur, 1982), it stands to reason that children with LI of different ages and different developmental stages may use gesture in different ways. In addition, some of the children in Iverson and Braddock's (2011) study were so young, many of those children may have been have been displaying a language delay, rather than a persistent language impairment. Children with milder language difficulties may use gesture in different ways to those who have persistent language deficits. For example, Thal and Tobias (1992), found that children with persistent language impairment did not differ from their TD peers in the number, type or function of gestures they produced; however, children with resolved early language delays used more communicative gestures than their TD peers. This suggests that children with transient and milder language difficulties were able to utilise gesture more readily as a compensatory mechanism than those children with persistent language impairment. Examining gesture use across the entire spectrum of language ability is important as it will help to ascertain whether differences in gestural abilities differentiate children with persistent language impairment from those with transient delays.

To overcome the limitations of previous research and address the conflicting findings in the field, the current study examined motor skill and gesture use within the same cohort of children with clinically significant language impairment, relative to typically developing children and children with low language and educational concerns.

The current study has a number of advantages over previous investigations: our participants were drawn from a population cohort, were all attending the same school year (thus reducing the age range within groups considerably), and motor, language and cognitive measures were available for all children. In addition, a graded set of gesture production variables were available for all participants, including (a) accuracy of gesture imitation and elicited single gestures, (b) frequency of spontaneous gestures in narrative and interactive problem-solving tasks and (c) functional use of those spontaneous gestures across narrative and problem-solving tasks. Thus the current study is uniquely placed to answer two key questions of theoretical and practical import: First, do children with language impairment have deficits in accuracy, frequency or function of gestures relative to age-matched peers, or peers with low language? Second, are measures of oral language and motor ability associated with gesture accuracy and/or gesture frequency?

If language and gesture are an integrated communicative system, we might expect children with LI to produce fewer accurate gestures and fewer extending gestures relative to TD peers and peers with low language. In contrast, if gesture can be used to compensate for oral language weaknesses, children with LI are expected to gesture more frequently, and to use more extending gestures than their TD peers, though gesture use might depend on task demands. Motor accuracy was predicted to be more closely related to gesture accuracy than gesture rate. Finally, if language and gesture are an integrated system, positive relationships between gesture and measures of oral language ability were anticipated in children with LI, as is the case in typical development. However, if gesture serves a primarily compensatory purpose in LI, a negative relationship might be evident, in which those with more severe linguistic deficits gesture more to enhance communication.

Our predictions regarding the low language group are more guarded; they represent an intermediate group who do not meet strict criteria for language impairment, but for whom milder language deficits are affecting classroom performance and teacher ratings of communicative competence. Thus we include them to ensure the full range of language ability is included in our sample. We anticipate that both accuracy and frequency of gesture use may be greater relative to LI and TD peers, based on previous investigations of children with resolved early language delay. However, this group may also elucidate residual communication deficits.

Method

Recruitment

Children were recruited as part of the Surrey Communication and Language in Education Study (SCALES), a population study of language impairment at school entry (Norbury et al., 2016). Reception class teachers completed the Children's Communication Checklist-S, (CCC-S, a short-form of the CCC-2, Bishop, 2003) for 7,267 children aged 4-5 years old in state-maintained schools in Surrey, a county in South East England (Stage 1). From this screen, the bottom 14% (stratified by season of birth and gender) of children were classified as high-risk (HR) for language impairment, whilst children scoring above this threshold were classified as low-risk (LR) of LI. Selection for Stage 2 used cut-off scores on the CCC-S for each of the three age-groups (autumn, spring, and summer born) to identify sex-specific strata of boys (13.9%) and girls (14.8%) with teacher ratings of poorer language relative to children of similar age and sex. In total, 636 monolingual children were invited to participate, with a higher sampling fraction for high-risk children (40.5% of high-risk boys, 37.5% high-risk girls) versus low-risk children (4.3% for boys, 4.2% for girls). In year 1, 529 children (83% of invited cohort) participated in an in-depth assessment of language, non-verbal cognition and motor skills (ages 5-6 years; 329 HR and 200 LR children, see Norbury et al., 2016, for details).

For the current gesture study, we aimed to visit approximately 10% of the total in-depth cohort, over-sampling high-risk children at a ratio of 2:1, HR: LR. One hundred and thirty families were contacted, inviting them to take part in the study, of which 50 families did not consent to take part in the study, a further eleven families initially consented, however suitable arrangements could not be made for the home visit. Sixty-three monolingual parent-child dyads (61 mother-child) consented and were observed for this study. There were no statistically significant difference between those families who opted in and those that opted out, on measures of social economic status, t(111) = -.08, p=.937, d=.02, speech and language concerns, χ^2=1.06, p=.304, or high risk status, χ^2=1.58, p=.209 (Opt-in: 41 high-risk; Opt-out: 38 high risk)

Defining Groups

Prior to the home visits for the current study, children completed an in-depth test of language and cognitive function at their school with a trained member of the SCALES research team. A total language composite score was derived from tests of expressive and receptive vocabulary (Brownell, 2010); receptive and expressive grammar (Bishop, 2003; Marinis, Chiat, Armon-Lotem, Piper, & Roy, 2011); narrative retelling and comprehension (Adams, Cooke, Crutchley, Hesketh, & Reeves, 2001). The core language battery consisted of tests that did not have current UK standardisations, either because they were standardised in North America, or were recently developed. Furthermore, co-standardising measures allows for direct comparison across measures. We therefore adjusted raw scores for child age using the full weighted SCALES sample (see Norbury et al. 2016 for details of this procedure). Children were categorised as LI (n = 21, 15 males) if their total language composite z-score was 1SD below the SCALES population mean. Typically developing (TD) children (n = 18, 8 males) were LR at screen and scored within the normal range on the total language composite. Twenty-one children were HR at screen, indicating communication skills ~1SD below the normative mean at school entry, but scored within the normal range on the total language composite two years later. These children obtained intermediate total language composite scores that were significantly lower than TD peers, and significantly higher than children with LI (Table 1). In addition, eight of these children are receiving special education support at school and six had previously been seen for speech and language therapy. Due to their history of language and communication concerns and ongoing special educational needs, they were not combined with the TD group, but instead formed an intermediate group of children with low language (LL) and educational concerns (n=21, 9 male). Including this intermediate group ensured that we could explore gesture use in relation to language across the whole spectrum of language abilities.

Participants

Sixty-three monolingual children aged 6-8 years participated in the current study. Three children with a known diagnosis of ASD were excluded from further analysis. The final sample of 60 comprised 18 TD (10 Female, 8 Male), 21 LL (12 Female; 9 Male) and 21 LI (6 Female; 15 Male) children (see table 1 for group characteristics). Participants had consented to be contacted for future studies as part of the SCALES consent procedures. Families were contacted by post and parents provided informed, written consent for participation in the study, including a home visit by the first author and video recording of all gesture tasks. The study protocol was approved by the Royal Holloway Research Ethics Committee.

Table 1

Means (SD) of background measures for children in each language group.

Measure	TD (n=18)	LL (n=21)	LI (n=21)	F	*p*	η^2
Age (months)	87.50 (5.53)	89.00 (5.11)	89.19 (5.54)	.56	.575	.02
Non-verbal ability	29.00[a] (4.86)	26.48[a,b] (3.57)	24.19[b] (3.68)	6.88	.002	.51
Language composite	.61[a] (.81)	-.40[b] (.45)	-1.67[c] (.62)	61.49	<.001	.68
Vocabulary Composite	174.11[a] (20.07)	154.05[b] (10.64)	129.71[c] (14.81)	40.76	<.001	.59
Number of words (Referential task)	654.28[a] (335.76)	576.67[a,b] (186.95)	455.10[b] (158.81)	3.62	.033	.11
Time taken in seconds (Referential task)	569.66 (249.80)	562.98 (224.23)	556.62 (182.69)	.017	.983	.001
Number of words (Narrative Task)	412.00[a] (106.41)	375.24[a,b] (65.61)	317.05[b] (123.44)	4.40	.017	.13
Time taken in seconds (Narrative Task)	191.30 (55.50)	188.99 (54.24)	203.17 (98.61)	.22	.800	.008

Note. All means are raw scores other than the language composite which is reported as a z-score. Different superscripts within the same row indicate differences between group means that are significant at p < .05

Procedure

Measures of oral language, non-verbal reasoning and motor skill were obtained as part of the larger SCALES battery. Children were seen at school by a trained member of the SCALES team when they were in Year 1 (age 5-6 years). Subsequently, gesture imitation and all gesture tasks were completed in the child's home by the first author. Each home visited lasted for approximately 90 minutes, with frequent breaks. Children completed all measures with the exception of three children who did not complete the gesture imitation task and one child whose elicited single gesture task data could not be used due to technical video error.

Background Measures

As previous research has focused on the link between vocabulary and gesture use (Rowe & Goldin-Meadow, 2009; Rowe et al., 2008), the current paper used a composite of the *Receptive One word Picture Vocabulary Test* (ROWPVT; Brownell, 2000b) and *Expressive One Word Picture Vocabulary Test* (EOWPVT; Brownell, 2000a), to index vocabulary. In addition, non-verbal IQ was assessed using the WISC *Block Design* (Wechsler, 2003).

Motor Skill

Children completed two subtests from the *Movement Assessment Battery for Children-2* (Henderson et al., 2007), posting coins and bead threading. The *Posting Coins* task require the child to post 12 coins into a money box as quickly as possible, first with their dominant hand and then with their non-dominant hand. Children were instructed to only pick up one coin at a time and to only use one hand to pick up the coins. The time it took each child to post all twelve coins in the box was recorded. The *Bead Threading* task required the child to thread six beads onto a piece of string as quickly as possible. The time taken to thread all six beads onto the string was recorded. A motor composite score was created combining time taken to complete both of these tasks. This task was measured in seconds whereby a lower (faster) time indicates more advanced motor ability.

Gesture Tasks

Gesture imitation task.

The motor sequence task from the NEPSY (Korkman, Kirk, & Kemp, 2007) was used to assess children's ability to produce the motor movements required for gesture production. This test includes 12 gesture sequences which become progressively more difficult. Gesture sequences included a combination of bimanual and unimanual sequences, moving the hands simultaneously, alternating between hands, and also included a combination of different hand position (e.g. in sequence: hand in a fist, palm down, palm to the side, clap,). The task started with a simple gesture sequences, such as moving both hands up and down simultaneously in a fist action. Following this the sequences became progressively more complex and longer, such as sequences that required the child to alternate their hands whilst producing different actions (e.g. Right hand fist, left hand palm down, right hand palm to the side, left hand fist).

The researcher demonstrated a motor sequence three times. The child was then asked to copy the sequence and repeat it five times. The child received a score of one each time they repeated the whole sequence correctly, giving a maximum score of 5 for each item and 60 for the whole test. The assessment was discontinued if the child scored zero on four consecutive items.

Elicited single gesture task

This elicited gesture task was an experimental task designed to examine how accurately children are able to produce meaningful gestures. This task was adapted from the gesture production task used by Botting et al. (2010), however the scoring criteria were developed specifically for this study. For this task, children were asked to describe eight different words without speaking (train, guitar, sleep walking, sad, climbing a ladder, monkey, painting, and sword fight). These words were chosen to provide a range of nouns and verbs that the child would already be familiar with. This task was designed to elicit bimanual representational gestures. As representational gestures are categorised as gestures that portray information about action, relative location and shape (McNeill, 1992) we coded children's ability to produce these elements correctly for all eight items. During initial coding it was noticed that children frequently produced two part gestures for certain items. For example, for climbing a ladder they gestured climbing, followed by ladder. To account for this five items were classed as two part gestures (climbing a ladder, monkey, train, sword fighting, sleep walking), whereby both actions were coded and three items classed as single part gestures (sad, painting, guitar). In addition, for the action 'climbing a ladder' an additional point was given if the child used both arms and legs, as this was deemed to demonstrate a clearer message than just using hands alone. Two part items had a maximum score of six (seven for climbing a ladder) whereas one part items had a maximum score of three. Thus, the overall maximum score for the whole task was 40.

All children completed the task, however, three children did not complete all items. As not all children completed all items and some items had higher scoring, we calculated a proportion accuracy score (accuracy score across items completed /maximum score on items completed*100). 10% of participant videos were double coded by a second rater, blind to the child's diagnostic group. Disagreements were resolved through discussion. The inter-rater reliability was 83% agreement, Kappa = .81 which indicates very good reliability (Landis & Koch, 1977).

Narrative Recall.

Each child watched four wordless cartoons (Die Sendung mit derMaus www.wdrmaus.de/lachgeschichten/spots.php5) that depicted a mouse and an elephant in different scenarios but did not include any verbal dialogue. The first cartoon was presented on a laptop screen, after watching the video the child was asked to re-tell the story to their parent, who had not seen the video (McNeill, 1992). This procedure was repeated for subsequent videos. Videos lasted between 30 and 60 seconds, were shown once and no specific instructions regarding story re-telling or using gesture were given. The order of presentation was counterbalanced across participants. 10% of participant videos were double coded by a second rater, blind to the child's diagnostic group. The inter-rater reliability for the narrative task was 80% agreement, kappa = .72 which indicates good reliability (Landis & Koch, 1977).

Referential Communication Task.

In this task, parent and child sat opposite each other and both had a board in front of them which the other could not see, though they could see each other. This task comprised four trials, the order of which were counterbalanced. Children and parents were assigned to either the describer or listener role. The child always started in the describing role and this alternated thereafter. The describer was given a board with eight different pictures of one animal (cats, dogs, mice or rabbits) displayed in a specific order on a 4x2 grid (see Figure 1 for example). The listener was given a blank board and 12 cards which included the eight target cards and four distractor cards. All drawings were in black and white and were designed to be visually similar. The describer was instructed to describe each of their cards and the order they appeared so that the listener could locate the correct card and place it in the correct position. Parents and children were free to communicate naturally throughout the task.

For the current analysis only data obtained when the child was in the describing role was included. 10% of participant videos were double coded by the 2nd and 3rd author, blind to the child's diagnostic group. Disagreements were resolved through discussion. The inter-reliability for the referential task 73% agreement, kappa = .70, which indicates good reliability (Landis & Koch, 1977).

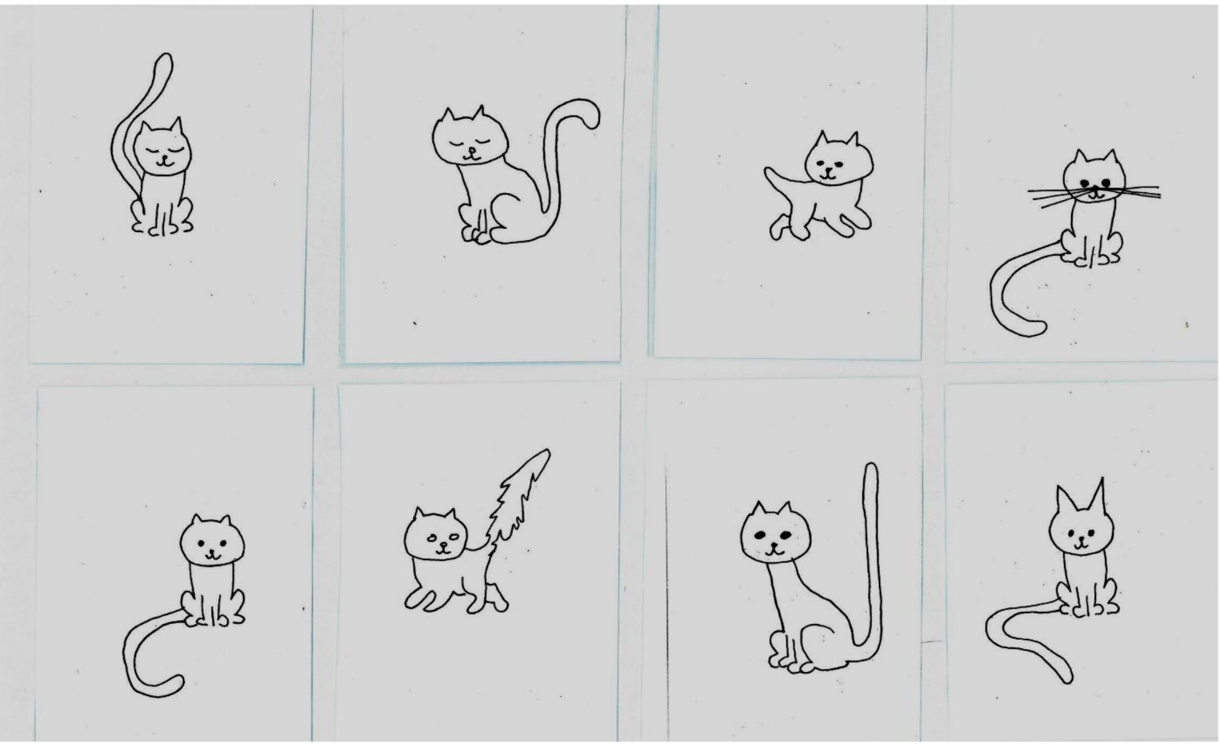

Figure 1: Example experimental stimuli for the Referential Communication task.

Verbal transcripts and gesture coding for the narrative and referential communication task.

Verbal dialogue in both tasks was transcribed using SALT (Miller & Iglesias, 2012). This was used to count the total number of words in each task. For both the narrative and referential communication task, videos were coded by the first and fourth author using The Observer XT software (Grieco, Loijens, Zimmermann, & Spink, 2013). The number of different gesture types produced by children during each of these tasks were coded. Gesture types included: Deictic gestures, which are pointing gestures used to draw attention to a particular object, person or location in the environment; Representational gestures, which show a close relationship to the object, action, idea or concept that they refer to (e.g. making a circular shape with hand to represent a ball); Conventional gestures which are culturally specific and convey meaning without the need for speech (e.g. nodding to symbolise yes); and Beat gestures, rhythmic movements which emphasises aspects of speech (McNeill, 1992). The total number of gestures (combining all gesture types) formed a raw gesture score. As language groups did not differ on the amount of time taken to complete each task, but did differ on the number of words spoken (see table 1), our gesture rate calculated the number of gestures per 100 words (number of gestures/ number of words*100) to provide a gesture rate that accounted for the number of words children used during each task.

Gesture function was also coded as either extending or redundant. Extending gestures included gestures that were produced with speech but which added extra information (e.g. "the cat had a tail like that", whilst simultaneously producing a curly tail gesture) and also gestures produced in isolation, in the absence of the verbal equivalent. Redundant gestures included gestures that reinforced the spoken message; although these gestures may highlight important aspects of an utterance, they do not add extra information to the utterance (e.g. "the cat had a curly tail", whilst simultaneously producing a curly tail gesture).

Table 2

Means (SD) for motor skill and gesture skill in all three language groups.

Measure	TD (n=18)	LL (n=21)	LI (n=21)	F	*p*	η^2
Motor skill (secs)	80.19[a] (20.55)	80.04[a] (12.72)	93.32[b] (17.13)	4.18	.020	.13
Gesture imitation	46.12[a] (9.03)	36.00[b] (10.53)	36.85[b] (10.21)	6.22	.004	.18
Elicited single gesture	62.47[a] (6.60)	56.13[a,b] (10.65)	49.13[b] (.13.19)	7.61	.001	.21
Narrative gesture rate	6.95 (3.11)	8.81 (4.47)	7.96 (5.00)	.89	.415	.03
Referential gesture rate	5.48[a] (2.10)	8.71[b] (2.19)	8.04[a,b] (5.11)	4.64	.014	.14

Note. *All data is raw data other than gesture rate which is number of gestures per 100 words. Motor skill was measured in seconds, whereby a lower (faster) time indicates more advanced motor ability. Different superscripts within the same row indicate differences between group means that are significant at $p < .05$.*

Results

Data analysis plan

The following analysis explores differences in child gesture rate and gesture function in relation child language ability. A series of ANOVAs was conducted to explore group differences in gesture frequency and gesture function across tasks. Cohen's d effect sizes are reported and interpreted as an effect size of .2 is a small effect, .5 a medium effect and .8 a large effect (Cohen, 1988). Group and task comparisons of the referential communication task focused on trials in which the child was in the describing role. Extreme outliers (more than three times the interquartile range) on the gesture and motor tasks were excluded from analysis. This included one child's referential communication data and one child's motor skill data.

Do children with language impairment have deficits in accuracy, frequency or function of gestures relative to age-matched peers, or peers with low language and educational concerns?

Time taken to complete the motor tasks, mean accuracy scores for gesture imitation and elicited single-word gesture task, and gesture rates in the narrative and problem-solving tasks are reported in Table 2. There was a significant main effect of language group on motor skill, *F* (2, 56) =8.08, *p*=.001, η_p^2 =.22. Post-hoc comparisons revealed that the TD and LL groups performed more similarly to one another and completed the motor task more quickly, indicating more advanced motor ability, than children in the LI group (TD vs. LI: *p*=.001, *d*=1.20; LL vs. LI: *p*=.010, *d*=.88). Thus as a group, children with LI have more demonstrable motor deficits relative to peers. We next considered qualitative differences in gesture production during gesture imitation and elicited, single-word gesture tasks. There was a significant main effect of language group on gesture imitation scores (*F* (2, 55) =6.22, *p*=.004, η_p^2 =.18). However, in contrast to the motor skill test, the LL group performed more similarly to the LI group, with both the LL and LI groups providing less accurate gesture sequences relative to TD peers, (LL vs. TD: *p*=.006, *d*=1.19, LI vs. TD: *p*=.015, *d*=1.03).

There was also a main effect of group in ratings of gesture quality during the elicited single gesture task (F (2, 56) =7.61, p=.001, η_p^2 =.21). As predicted, the gestures of children in the LI group were rated as significantly less accurate than the TD group (p=.001, d=1.28). No significant differences were found between children with LL and either of the other two groups.

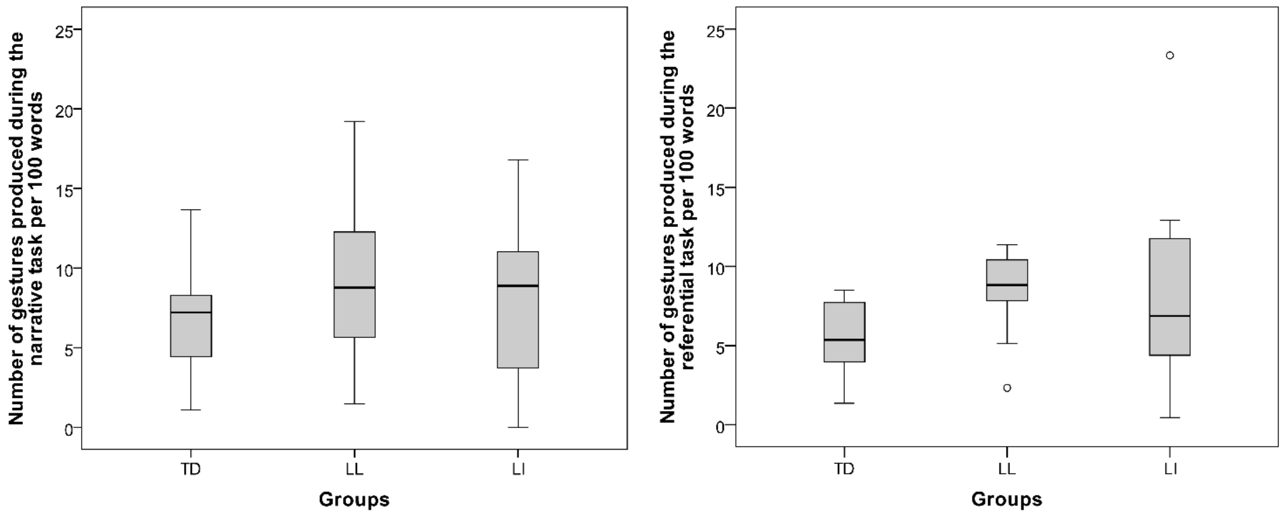

Figure 2. Number of gestures per 100 words produced by children during the narrative task and referential communication task.

We next considered gesture rate in more naturalistic tasks of story-telling and interactive problem-solving. As illustrated in Figure 2, there was considerable within group variation in both tasks. In the narrative task, there were no significant group differences in the rate at which children produced gestures, F (2, 57) =.89, p=.415, η_p^2 =.03. In contrast, during the referential communication task there was a significant main effect of language group, F (2, 57) =4.42, p=.016, η_p^2 =.14. These data violated assumptions of homogeneity (F (2, 56) =6.36, p=.003), therefore the Games-Howell correction was applied in post-hoc analysis. Here it was clear that the LL group gestured significantly more frequently than the TD group (*p*=<.001, *d*=1.50), but there was no significant difference between the LI and TD groups (*p*=.108, *d*= .07).

Figure 3 illustrates that in general, all children use gesture to reinforce their spoken message, as indicated by the large proportion of redundant gestures. This is particularly true in the narrative task, and children with LI did not differ from their peers in terms of the function of gestures (e.g. extending or redundant) they produced during the narrative task. However, there was a main effect of group on gesture function during the interactive problem-solving task, $F(2, 56) = 8.40$, $p= <.001$, $\eta_p^2 =.23$. As expected, children with LI produced significantly more extending gestures than either the TD (*p*=.030, *d*= .84) or LL (*p*=.002, *d*= 1.15) groups. Thus, during an interactive and cognitively demanding task, children with LI use gesture to convey more complex messages than are realised verbally.

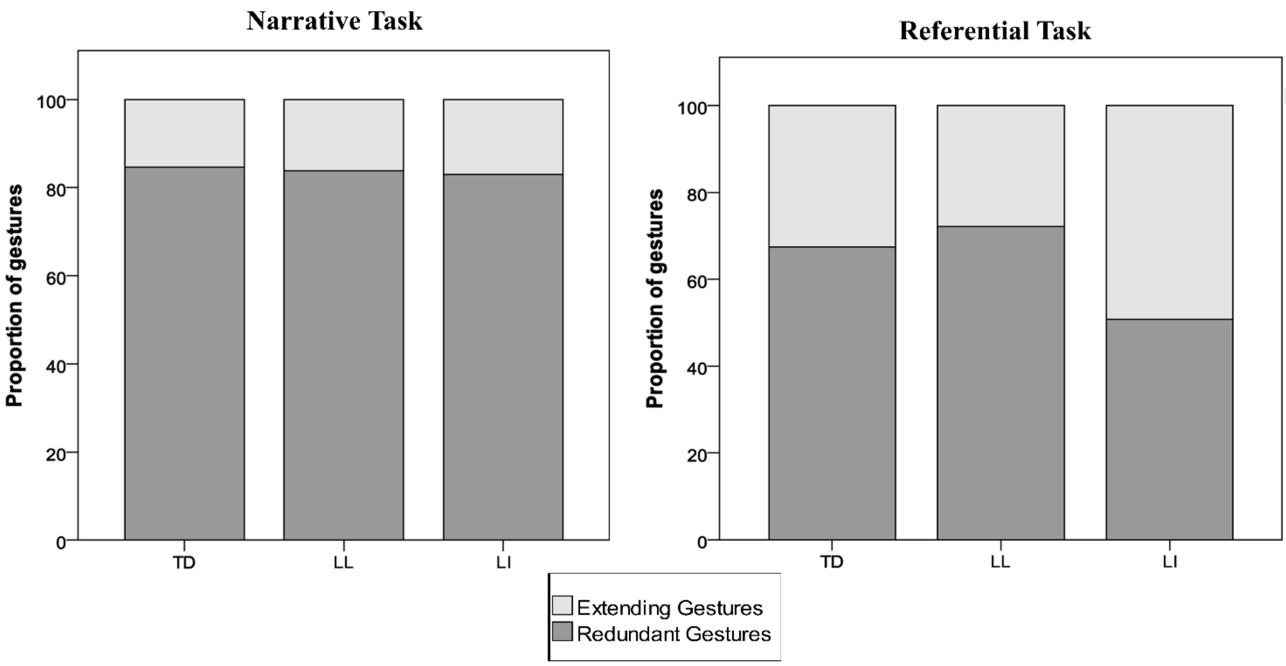

Figure 3. The proportions of extending and redundant gestures produced by children during the narrative and referential communication tasks.

Secondary Analysis

It may be that the inclusion of the intermediate LL group may have resulted in a more able TD group, and thus exaggerated the differences between the TD and LI groups. To explore this, we re-analysed the data, combining the TD and LL group. Children who had a history of speech and language therapy or had special educational support at school were excluded from analysis (n=15). The following analysis indicates that the LI group still scored significantly lower than their TD peers on measures of language and non-verbal reasoning (see table 3). Children with LI also displayed significantly more motor difficulties than TD peers, F (1,42) =13.74, p<.001, d=1.10, and produced significantly less accurate gesture sequences during gesture imitation, F (1,41) =6.62, p=.014, d=.79. In addition the gestures of children with LI were rated as significantly less accurate than TD peers during elicited gesture task, F (1,43) =12.02, p=.001, d=1.02.

Next we re-analysed data from spontaneous communication during a naturalistic tasks of story-telling and referential communication. In the narrative task, there were no significant group differences in the rate at which children produced gestures, F (1,42) =.07, p=.790, d= .08. Similarly, during the referential communication task there was no significant difference between the LI and TD group, F (1,42) =.78, p=.381, d= .26.

Finally, our analysis indicated that LI children did not differ from their TD peers in terms of the function of gestures (e.g. extending or redundant) they produced during the narrative task, F(1,41)=1.28, p=.83, d=.09. However, there was a main effect of language group on gesture function during the interactive problem-solving task, children with LI (Mean: 49%) produced significantly more extending gestures than the TD (Mean: 31%) group, F(1,42) = 9.92, p=.003, d= .94.

Table 3

Means (SD) for background measures, motor skill and gesture skill.

Measure	TD (n=24)	LI (n=21)	Range	F	*p*	*d*
NV-Reasoning	28.25(3.97)	24.19 (3.68)	16-38	15.23	<.001	1.06
Language composite	.25(.86)	-1.67 (.62)	-3.11-1.86	55.18	<.001	1.89
Vocabulary Composite	167.21(20.02)	129.71 (14.81)	81-207	78.81	<.001	2.13
Gesture imitation	43.87(8.93)	36.85 (8.93)	20-58	6.62	.014	.79
Elicited single gesture	60.3(8.12)	49.13(13.19)	15-70	12.02	.001	1.02
Narrative gesture rate	7.6(3.96)	7.96(5)	0-19.2	.07	.790	.08
Referential gesture rate	7.61(3.67)	8.05(5.11)	0.45-23.33	.78	381	.26

Are measures of language and motor ability associated with gesture accuracy and/or gesture frequency?

For the following analysis children in all three language groups were analysed as a whole. As can be seen in table 4, significant negative correlations were found between motor skill and gesture accuracy in both gesture imitation (*r*(57)= -.345, *p*=.009) and elicited single-word gesture tasks (*r*(58)= -.566, *p*<.001). This demonstrates that children with greater motor skill produce more accurate gestures. However, there was no significant relationship between motor skill and gesture rate for either the narrative task (*r*(59)= -.174, *p*= .188) or the referential task (*r*(58)= .053, *p*= .694).

There was a significant positive correlation between vocabulary and gesture accuracy in the gesture imitation task (*r*(60)=.503, *p*<.001) and elicited single gesture task (*r*(59)=.552, *p*<.001) (Table 4); this relationship was similar across all three language groups (Figure 4). This indicates that, overall, children with more advanced vocabulary produced more accurate gestures than those with poorer vocabularies. Somewhat surprisingly, gesture rate (both narrative task and referential communication task) and gesture accuracy were not significantly correlated (Table 4). Although gesture rate during narrative recall was not significantly correlated with vocabulary ($r(60)=-.039$, $p=.766$), gesture rate during referential communication was significantly negatively correlated with vocabulary level ($r(59)=-.320$, $p=.014$). This suggests that during the interactive task, those children with more severe vocabulary deficits gestured more frequently than those with more advanced vocabulary. In addition, different patterns of association between gesture rate and vocabulary were evident across the three language groups (Figure 4). Figure 4c illustrates the negative relationship between vocabulary and gesture rate during narrative recall for both the LL and LI groups, as well as the expected positive relationship within the TD group. Similarly, figure 4d shows the negative relationship between vocabulary and gesture rate during referential communication task for the LI group, a relationship also seen for the TD group. However, a positive relationship is seen between vocabulary and gesture rate for the LL group during this task. However, due to small sample size these relationships are not significant at the group level. However, this result was attenuated when the outlier observed in Figure 4d was removed ($r(58)= -.127$, $p=.341$). It should be noted that this child had the most severe expressive language deficits, and relied heavily on gesture to communicate. However, this child also scored poorly on measures of gesture imitation and gesture elicitation. The extreme scores are not spurious and reflect the child's true language profile and thus give some insight into the use of gesture when verbal expression is severely limited.

In addition, vocabulary was also significantly negatively correlated with the proportion of extending gestures produced during referential communication ($r(59)=-.390$, $p=.002$), again indicating that those children with more severe language difficulties were using proportionately more extending gestures than children with more advanced language abilities.

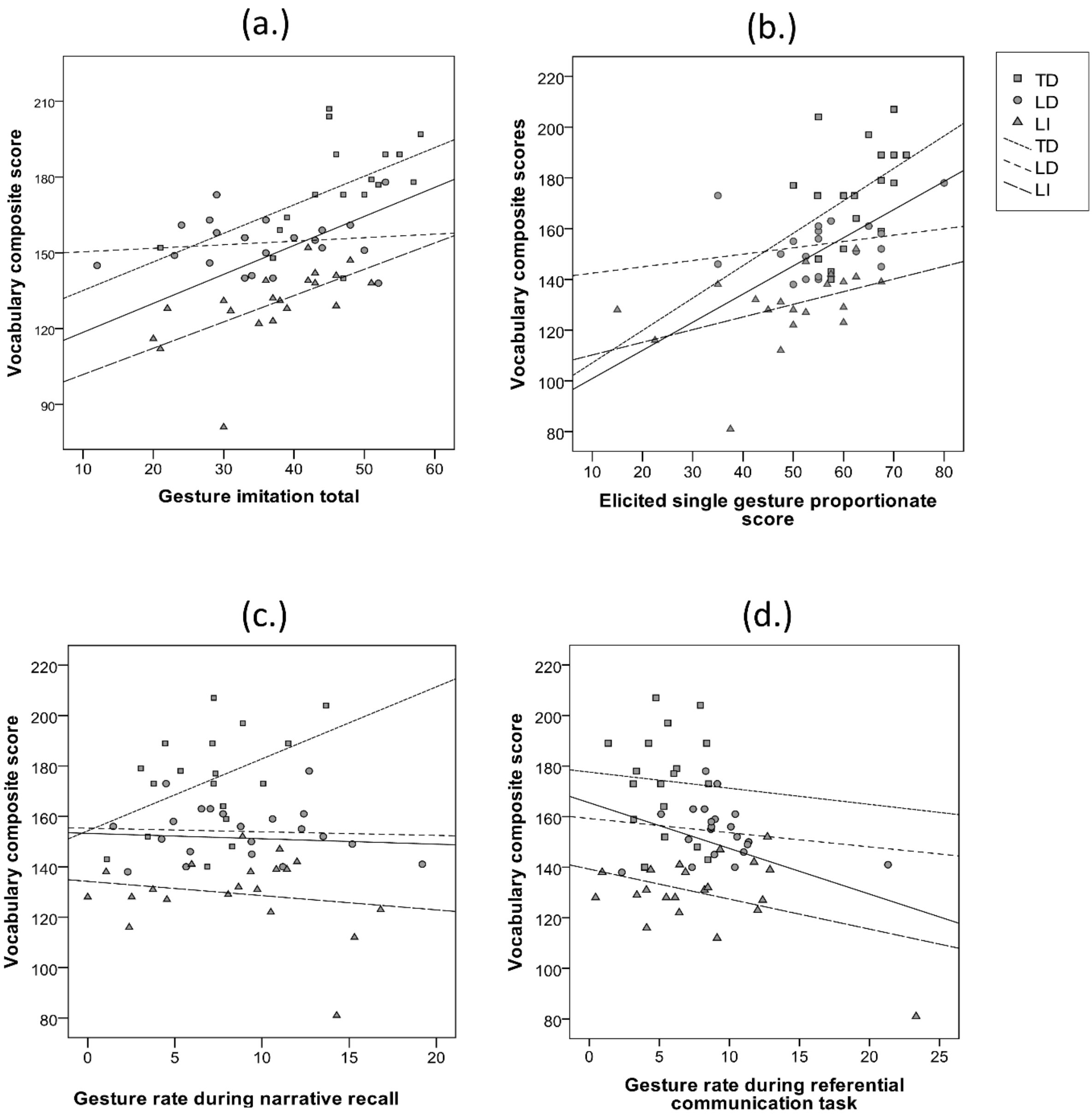

Figure 4: Scatterplots showing the relationships between Vocabulary and (a) gesture imitation, (b) elicited gesture production, (c) gesture rate during narrative recall and (d) gesture rate during referential communication.

Discussion

This study explored gesture accuracy and gesture frequency in children with LI on measures of meaningless gesture sequence imitation, meaningful elicited gesture production and spontaneous gesture production, using both narrative monologue and interactive problem-solving tasks. In addition, we considered whether gesture accuracy and/or frequency were related to child vocabulary, and whether gesture was related to underlying motor competence. Our key findings were that children with LI gestured as frequently as peers, and in complex tasks produced more extending gestures to convey information they could not verbalise. Nevertheless, the gestures they produced in imitation and elicitation tasks were not as accurate as those of their peers. Importantly, accuracy was moderately correlated with both vocabulary knowledge and underlying motor skill. We consider the implications of these findings in relation to our initial hypotheses below.

The present study confirmed that many children with LI also have a co-occurring motor deficit (cf. Johnston, Stark, Mellits, & Tallal, 1981; Powell & Bishop, 1992). In addition, children with LI also have difficulties imitating meaningless gesture sequences, in comparison to TD peers. At first glance, these findings appear to contradict Wray et al. (2015), who found no differences between children with LI and age-matched peers on a gesture imitation task. Crucially, however, Wray et al. (2015) only required children to imitate hand positions and not hand sequences. Taken together, these findings indicate that children with LI have difficulties with producing gesture sequences which are arguably more closely related to naturalistic gesture than imitating hand position only. Interestingly, children with LL exhibited gesture imitation abilities that more closely resembled the LI group than the TD group. This suggests that children with mild language difficulties have subtle deficits in motor movements that are in keeping with their oral language abilities.

During meaningful elicited single-word gesture production, we again saw evidence that children with LI demonstrate relative weaknesses in their ability to produce accurate gestures in comparison to TD peers, consistent with previous investigations (Hill, 1998; Wray et al., 2015). Notably, Botting et al. (2010) did not find less accurate gesture production in children with LI. However, participants in Botting et al. were younger than those in the current study, raising the possibility that differences in gestural skill become more apparent over the course of development.

Additionally, some of the younger children may have been exhibiting early language delay, rather than persistent language impairment, consistent with our LL group findings. In contrast, the LL group did not demonstrate accuracy weaknesses during elicited single word gesture production despite showing impairments in gesture imitation. This task required children to have well-developed semantic representations for each word in order to produce an accurate gesture; thus these results may reflect more limited semantic knowledge in the LI group, relative to the LL group (cf. Capone, 2007). In addition, pragmatic language abilities may also have influenced the ability of children with LI to understand the linguistic context and tap into their pre-existing knowledge and experience of target words, or their ability to express concepts succinctly. For example, they often provided either too little or too much detail in their gestures, making it difficult for the observer to clearly understand the intended word.

In the current study, children with LI did not gesture more frequently than their peers during either the narrative or the interactive problem-solving task, in contrast to previous reports Iverson & Braddock, 2011; Mainela-Arnold et al., 2014). Instead, children with LI gestured at the same rate as their peers, suggesting that even though their gestures are less accurate, they remain motivated to use gesture during communication. Children with LL, on the other hand, did gesture more frequently than their TD peers, again highlighting differences between children with low language and those with persistent language impairments. Given that children within the LL group were identified as having language and communication difficulties during their first year of school, but did not meet criteria for LI two years later, some of these children may have had language difficulties that have now resolved. If so, then these findings are consistent with Thal and Tobias (1992) who reported that children with resolved language delay gesture more frequently than their TD peers. This further suggests that gesture rate may be an important prognostic indicator of persistent LI in children with early language deficits.

Children with LI did use a greater proportion of gestures that extended utterances, rather than just reinforcing the verbal message, particularly in the interactive problem-solving task. This highlights an important function of gesture for children with LI; they may not use gesture more frequently than their peers, but they may be using gesture to convey ideas that they are unable to express verbally by using gesture to replace those words. This is consistent with Blake et al. (2008) and Evans et al., (2001) who also found no differences in gesture rate, but evidence that a greater proportion of gestures used by children with LI were extending gestures. The fact that this compensation was more evident during an interactive problem-solving task suggests that children with LI may only use gesture to compensate when the cognitive demands of the task are high. Nevertheless, the fact that the gestures they produce are less accurate suggests that these attempts to compensate may not be consistently successful.

It could be argued that these differences have been exaggerated because our TD group did not include children rated as ‘high-risk’ on the teacher screen, who may in fact be false positives. If so, the TD group does not represent the full range of language abilities and is therefore a ‘super’ ability TD group. However, our results remained unchanged when we combined the TD group with those children with LL who were not receiving specialist support for their communication challenges. In addition, our correlational analyses take account of the entire sample, ensuring that our findings are not limited to those at the extremes of the distribution.

In addition, disparities in NVIQ between LI and TD group may also have influenced the findings. We did not control for NVIQ in our analysis as it is not unusual to find that children with LI have significantly lower NVIQ relative to TD children, even if they are selected to have NVIQ within the normal range (NVIQ > 70 ; Norbury et al., 2016). In addition it is not appropriate to use ANCOVA when the co-variate is non-randomly associated with group membership, as NVIQ is in this case (Miller & Chapman, 2001, and Dennis et al. 2009). Finally, whilst both language and non-verbal ability were associated with the imitation and elicitation measures, the direction of causal influence cannot be determined from this study alone. Language, motor and NVIQ are all highly correlated within this population and likely reflect atypical brain development, but may not be causally related to one another.

The significant relationships found between motor ability, gesture imitation and vocabulary with gesture accuracy again provides support for the idea that motor and language abilities are intimately related to gesture accuracy. The significant negative correlation between gesture rate during interactive problem solving and vocabulary across the whole sample, again suggests that increased gesture rate is associated with lower levels of language competence. The fact that this relationship was only seen during complex parent-child interaction and not narrative recall, along with increased use of extending gestures, suggests that children are more likely to use gesture to compensate when task demands are high. In addition, the significance of this relationship was partially driven by an outlier with extremely limited expressive language abilities. If our sample included more children with such extreme verbal language limitations, the negative relationship would likely have been stronger.

It is notable that within all three language groups there was wide variation in gesture rates that is not fully accounted for by the child variables measured here. Previous research with young, typically developing children has identified parent gesture use and socio-economic status as important factors in explaining individual differences in gesture use in young children (Rowe et al., 2008). Investigation of these parental and environmental factors in different language groups could be enlightening, and is something we are currently investigating. Longitudinal data is also necessary to begin to elucidate the causal relationships between these variables, for example, whether gesture is predictive of later language in this population or whether diminished semantic representations adversely impacts gesture production. Intervention paradigms that employ gesture to enhance oral language may provide further insight into the causal relationships between language, gesture and motor skill.

Theories of communication vary in the extent to which spoken language and gesture are viewed as complementary or integrated systems. In typical development, there is considerable evidence that they are integrated systems, intimately related and mutually supporting development of the other. Investigation of atypical development is therefore crucial as such tight relationships may become unravelled. Our data, however, provide some mixed evidence. To some extent these systems are complementary; children with LI gesture as much (though not more) than TD peers, and can use gesture to express ideas that are not realised in spoken output. However, these compensatory uses of gesture are most evident when task demands are high and/or when verbal output is severely limited and gesture is the only way to communicate. Furthermore, children with LI displayed difficulties with both meaningless and meaningful gesture production, indicating that when there is language breakdown, difficulties with gesture production are also seen. This finding supports the hypothesis that gesture and language form an integrated communication system. Nevertheless, this does not hinder children's motivation to use gesture to communicate. Despite difficulties with both verbal and gestural communication children with LI still have a typical drive to communicate both verbally (Bishop, 200) and non-verbally. Thus providing them with the opportunity to use extending gestures to compensate for their language weaknesses. Unfortunately, the gestures they produce may not be as accurate or as informative as gestures produced by TD children, and this may limit the ability of interlocutors to comprehend the gestures produced by children with LI. The differences in gesture use between the LI and LL group suggest that gesture may serve as a means to differentiate between children with low language and those that may have persistent language difficulties. The results also indicate that it is the quality, not quantity of gestures that differentiates the non-verbal communicative abilities of children with LI from their peers.

Acknowledgements:

This research is funded by grants from the Wellcome Trust (WT094836AIA) to C.F.N and the Waterloo Foundation to C.W. and C.F.N. We extend a warm thank you to all of the children and parents who took part in this study.

Author statement:

Recruitment, data collection and coding was completed by the first author under the supervision of the last author. The second, third and fourth author transcribed the tasks and assisted with gesture coding and reliability checking.

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