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Gesture-Speech Integration Is Related to Vocabulary Skills in Children with Developmental Language Disorder, Williams Syndrome, and Typical Development.

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Data availability statement

Due to the nature of this research, participants of this study did not agree for the raw data (video, audio) to be shared publicly. The processed anonymised data that support the findings of this study are available upon reasonable request from the corresponding author, ER.

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Conflict of interest disclosure

There was no conflict of interest and there were no restrictions on the publication of results.

Ethics approval statement

The procedures have been approved by the Research Ethics Committee UZ/KU Leuven (protocol number B322201835033).

Participant consent statement

The children's parents gave written informed consent and the participating children oral assent.

Keywords: Iconic gesture; Williams syndrome; Language disorder; Co-speech gesture

Abstract

Background: Individuals with developmental language disorder or Williams syndrome are reported to use more gestures than individuals with typical development. However, these two groups considerably differ in visuospatial skills and language skills, two skills that are hypothesised to shape gesture rate.

Aims: We first examined whether children with developmental language disorder and with Williams syndrome do indeed use more gestures. Our second aim was to disentangle the role of vocabulary and visuospatial skills in the use of supplementary gestures (i.e., containing unique information). To account for participant heterogeneity, analyses included both group comparisons and vocabulary and visuospatial skills at an individual level. As a third aim, the role of visuospatial skills was further examined in relation to gestures containing spatial content.

Methods & Procedures: In a cross-sectional group design, three participant groups watched and then retold a cartoon: children with typical development (n = 25), children with developmental language disorder (n = 25), and children/young people with Williams syndrome (n = 14). Their narrations were transcribed, and hand gestures were coded based on gesture-speech integration (redundant, adds information to particular lexical items, gives information that is entirely absent from speech) and spatial content. Participants' expressive vocabulary and visuospatial skills were measured.

Outcomes & Results: Between-group comparisons showed that individuals with developmental language disorder or Williams syndrome did indeed use more gestures. Poisson loglinear modeling demonstrated that a relative higher use of supplementary gestures was determined by lower expressive vocabulary skills. Neither the group distinction nor visuospatial skills shaped the supplementary gesture rate nor spatial gesture rate.

Conclusions & Implications: Regardless of neurodevelopmental condition or typical development, a higher use of supplementary gestures was influenced by expressive vocabulary skills. Children with lower vocabulary skills spontaneously capitalized on the multimodality of communication to express constituents that were not present in their verbal speech. This finding is a promising starting point for future gesture intervention studies examining whether implicit modeling of gesture use can encourage gestures even more in these children and whether this allows them to achieve higher linguistic complexity. On a methodological note, the observed intra-group skill variability demonstrates that group comparisons need to be complemented with correlational measures accounting for skills at an individual level.

What this paper adds

What is already known on the subject

- Children with developmental language disorder and children with Williams syndrome are more inclined to use gestures than typically developing children. Research conducted in adults with typical development points towards the role of lexical and visuospatial skills in gesture use but it is unclear how these skills shape gesture use in children with atypical development.

What this paper adds to the existing knowledge

- This study compares the rate of gestures that convey meaning that is not expressed in speech between the three afore-mentioned populations. Novel is the inclusion of the group distinction, individual lexical skills, and visuospatial skills in one encompassing statistical model.

What are the potential or actual clinical implications of this work?

- The inclination to use gestures that replace speech is related to lexical skills. Visuospatial skills do not seem to play a role and should not be considered as a factor when thinking about gesture intervention. Understanding how gestures relate to specific skills is a first step in understanding how gesture interventions can bolster language production.

Gesture-Speech Integration Is Related to Vocabulary Skills in Children with Developmental Language Disorder, Williams Syndrome, and Typical Development.

INTRODUCTION

Iconic gestures “bear a close formal relationship to the semantic content of speech” (McNeill, 1992, p.12). As these gestures visually depict semantic features of concepts and consequently have high communicative value (Kendon, 2005), the use of natural, iconic gestures has been targeted in some communication interventions for individuals with language disorders (e.g., Calculator and Diaz-Caneja Sela, 2015; van Berkel-van Hoof *et al.*, 2019). Nevertheless, little is known about the relation between cognitive skills and the inclination to use natural, iconic gestures. Expressive lexical skills and the ability to visualise concepts may shape gesturing frequency but research findings diverge (Chu *et al.*, 2014; Hostetter and Alibali, 2007; Wray *et al.*, 2017). To gain insight into the role of these skills in the gesturing frequency of children with atypical development, the present study examined the use of spontaneous, iconic gestures in participants who typically differ with regard to these skills: children with developmental language disorder, individuals with Williams syndrome, and a neurotypical control group.

Developmental language disorder & Williams syndrome

The delineation of developmental language disorder has been debated, but Bishop *et al.* (2017) have developed criteria to outline the diagnosis. Children with developmental language disorder may experience expressive and/or receptive language problems in different areas, such as grammar, semantics, phonology, pragmatics (Bishop *et al.*, 2017). The language disorder cannot be explained by biomedical conditions such as autism spectrum disorder. Finally, the children may have lower nonverbal skills, which is typically measured using visuospatial tasks such as a block design task (e.g., Wray *et al.*, 2017), that are not low enough to indicate intellectual disabilities. As a result of diverging and altering inclusion criteria, some gesturing studies only included children with language disorder who had a nonverbal intelligence quotient above 85 (e.g., Blake *et al.*, 2008; Mainela-Arnold *et al.*, 2014) whereas other studies included children who were allowed to have low nonverbal skills (e.g., Wray *et al.*, 2017). This complicates interpretation of group differences.

The diagnosis of Williams syndrome is established through genetic testing. This rare genetic disorder typically presents itself through: (a) mild to moderate intellectual disabilities, (b) fine and gross motor difficulties, (c) vocabulary and grammar skills that are strong or average relative to their developmental age, (d) strong or average non-verbal reasoning, and (e) low visuospatial and spatial-motor abilities (Brock *et al.*, 2007; Mervis and John, 2008). Performance on visuospatial tests, such as the block design, is a considerable weakness for individuals with Williams syndrome (Berencsi, Gombos and Kovacs, 2016; Farran and Jarrold, 2003; Mervis and John, 2008). While they may also have difficulties with expressive vocabulary, their visuospatial deficit is often considerably larger than their expressive vocabulary difficulties (Brock *et al.*, 2007).

Considering these group profiles, the match between lexical and visuospatial skills differs between children with developmental language disorder, with Williams syndrome, and with typical development. In children with developmental language disorder, the match between verbal and visuospatial skills is either balanced, in the case of low nonverbal skills, or in favour of visuospatial skills. In contrast, in individuals with Williams syndrome, this balance is more likely in favour of the verbal skills. Even though individuals with developmental language disorder and individuals with Williams syndrome have distinct cognitive profiles concerning their lexical and visuospatial skills, they both produce more gestures than participants with typical development (Bello, Capirci and Volterra, 2004; Mainela-Arnold *et al.*, 2014; Mastrogiuseppe and Lee, 2017; Wray *et al.*, 2017).

Gesture-speech integration

In speech-language pathology, researchers have focused on how co-speech may facilitate communication in individuals with communication difficulties by examining gesture-speech integration (e.g., Bello *et al*., 2004; Mainela-Arnold *et al.*, 2014; Mastrogiuseppe and Lee, 2017; Wray *et al.*, 2017). Gesture-speech integration indicates the extent to which a gesture does or does not add information to speech. Whereas redundant gestures provide no additional information, complementary gestures add information to speech (Wagner, Malisz and Kopp, 2014). For example, a child may say “and then he went to the left” while (redundantly) swinging an arm to the left. If the child says “and then he goes over there” while swinging an arm to the left; the gesture adds to the speech given that a direction is lexicalised (“there”) but not specific. Some authors argue that gestures are always complementary as the visual modality always expresses some additional information because it is a different sensory modality than speech (Colletta *et al.*, 2010). In some studies on atypical language, authors have also considered supplementary gestures, which are gestures that provide information in absence of accompanying lexical items (e.g., Mainela-Arnold *et al*., 2014; Mastrogiuseppe and Lee, 2017). A supplementary gesture conveys semantic content that is not expressed in speech. For example, Mainela-Arnold *et al.* (2014, p.761) cite an example from McNeill whereby the verbal expression "she chases him out again" is combined with a simultaneous gesturing of a swinging umbrella. The specifier or the manner of chasing (i.e., swinging an umbrella) is not represented in speech and is only fulfilled through gesture. The distinction between complementary and supplementary will be made in the present study's design because supplementary gestures in particular are considered to compensate for expressive language difficulties (Mastrogiuseppe and Lee, 2017). However, when discussing findings from studies that did not make this distinction, the encompassing term "non-redundant" will be used here. Table 1 provides examples of gesture-speech integration.

Table 1. Examples of gesture-speech integration in iconic gestures from participants with developmental language disorder

Redundant	Non-redundant	
	Complementary	Supplementary
"And <u>then it flew</u>" (extended arms moving vertically at sides)	"And then <u>the bird flies</u>" (fist moving from left to right with hopping motion)	"The bird <u>like …</u>" (extended arms moving vertically at sides)

Note. Underlined lexical items indicate simultaneity of speech and gesture.

Children may use supplementary gestures because they have difficulties conveying this information through speech. In early language development, supplementary gestures are considered as lexical fillers because they allow for multisymbol combinations without the need to use the lexical item (Capone and McGregor, 2004). During typical language development, the rate of supplementary gestures decreases with increasing age and expressive language skills (Alibali, Evans and Hostetter, 2009; Lavelli and Majorano, 2016; Mainela-Arnold *et al.*, 2014). While retelling a cartoon, 6- to 10-year-old children with typical development produced iconic gestures in 4 to 8% of their clauses and very rarely used supplementary gestures (Colletta *et al.*, 2010). Children with developmental language disorder and children with Williams syndrome both use a higher number of supplementary gestures compared to (mental-)age matched peers (Blake *et al.*, 2008; Lavelli and Majorano, 2016; Mainela-Arnold *et al.*, 2014; Mastrogiuseppe and Lee, 2017).

Not only the absolute number of supplementary gestures but also the number of supplementary gestures proportional to the overall gesture use is higher in children with developmental language disorder and children with Williams syndrome than in age-matched peers. Using a cartoon retell task, Mainela-Arnold *et al.* (2014) observed that primary-school aged children with developmental language disorder used a higher number of redundant and non-redundant gestures than participants with typical development, but the distribution of gestures across these two categories was similar in both participant groups. Nevertheless, Wray *et al.* (2017) found that during more demanding descriptive tasks, children with developmental language disorder used a similar number of iconic gestures as children with typical development but with a higher proportion of non-redundant gestures. The authors argued that the task's higher cognitive demands combined with the children's language difficulties resulted in a higher cognitive load for the children with developmental language disorder, which gave rise to a proportionally higher reliance on non-redundant gestures. Similarly, during a cartoon retell task, participants with Williams syndrome produced relatively more supplementary gestures during a narrative task compared to mental-age matched participants with typical development (Mastrogiuseppe and Lee, 2017).

Supplementary gestures, vocabulary skills, & visuospatial skills

Given that typically developing children have lower verbal skills than adults with typical development, children may rely relatively more on the visual modality than on spoken words (Alibali *et al.*, 2009). To study vocabulary skills as a potential factor underlying increased gesture use, researchers have examined gesture frequency during naming tasks (Bello *et al.*, 2004; Lavelli and Majorano, 2016). During a naming task, preschool children with developmental language disorder produced a higher number of both redundant and supplementary gestures compared to age matched children with typical development but not compared to language matched children (Lavelli and Majorano, 2016). The authors considered impaired phonological representation as a possible explanation for this observed preference for using gestures over exclusively spoken utterances. Similarly, Bello *et al.* (2004) argued that vocabulary skills underlie increased gesture use in young children with Williams syndrome. They presented the Boston Naming task (Kaplan, Goodglass and Weintraub, 1983) to young participants with Williams syndrome, mental-age matched children, and chronological-age matched children with typical development. During the Boston Naming task, participants with Williams syndrome produced more supplementary gestures and redundant gestures compared to mental-age matched children with typical development even though they performed equally well on the naming task (Bello *et al.*, 2004). While this finding may at first sight indicate that vocabulary skills were not related to increased gesturing, the authors argued that the increased gesturing by participants with

Williams syndrome was indicative of less efficient lexical retrieval because the response times during the naming task were higher in the participants with Williams syndrome than in the mental-age matched peers.

Because supplementary gestures have been observed very rarely during naming tasks as participants typically provided some verbal response (Bello *et al.*, 2004; Lavelli and Majorano, 2016), retell tasks are better suited to study supplementary gestures and their relation to vocabulary skills (e.g., Blake *et al.*, 2008; Mainela-Arnold *et al.*, 2014; Mastrogiuseppe and Lee, 2017). In the study by Wray *et al.* (2017) on the gesture use of children with developmental language disorder and children with typical development, vocabulary skills correlated negatively with the rate of non-redundant gestures. The authors remarked that this correlation was largely caused by outliers, children with severe vocabulary deficit who used considerably more gestures. Nevertheless, in children with typical development too, there appears to be an association between language skills and non-redundant gestures. Using a retell task, Alibali *et al.* (2009) analysed the occurrence of non-redundant gestures (i.e., complementary and supplementary), in relation to dysfluencies in children with typical development aged between 5 and 10 years. Compared to adults, children produced more dysfluencies and were more likely to produce non-redundant gestures during these dysfluencies. This higher use of non-redundant gestures during dysfluencies suggests an association between children's language processing and the use of non-redundant gestures. However, because language skills and their relation to gesture use during dysfluencies were not measured, this relation remains tentative.

Findings from studies on the relation between lexical skills and gesture use in adults with typical development diverge (Chu *et al.*, 2014; Hostetter and Alibali 2007, 2011). Using both a short cartoon retell task and a description task whereby participants described how they would wrap a present, Hostetter and Alibali (2007) found a quadratic relation between phonemic fluency and gesture frequency: adults with low and high phonemic fluency were significantly more inclined to use gestures than adults with average fluency. While the rate of supplementary gestures was not examined, the authors hypothesised about the relation between supplementary gesture rate and low lexical skills when they wrote that the increased gesture use could be: "to compensate for their poorer verbal skills, either by helping themselves translate their ideas into speech or by eliminating the need to translate the ideas into speech at all" (Hostetter and Alibali, 2007, p.90). Using a word definition rather than cartoon retell task, Chu *et al.* (2014) came to a different result as they found no correlation between gesture use and performance on a picture naming task. The authors argued that a possible explanation for this lack of correlation could lie in the fact that the task allowed participants to choose their words freely and that the task may have been lexically less demanding. This aligns with the gesturing data from Hostetter and Alibali who observed that about a third of participants did not gesture during the retelling of the 90-sec children's cartoon, an easy task that would have posed few demands on the adults' lexical retrieval. Most gesturing occurred during the present wrapping description task where only 7% of participants did not gesture.

Visuospatial skills and the ability to visualise, hold, and manipulate mental images may shape gesturing (Chu *et al.*, 2014; Hostetter and Alibali, 2007, 2011, 2019). Concepts that are conveyed through iconic gesture contain both spatial and motoric information (Hostetter and Alibali, 2019; Taub, 2001). For the present participant groups, only one study looked into the relation between visuospatial skills and supplementary gestures. Wray *et al.* (2017) found no correlation between performance on a block design test, overall gesture use, and proportional use of non-redundant gestures in children with typical development and children with developmental language disorder.

In adults with typical development, three studies examined both lexical skills and visuospatial skills in relation to overall gesture use (Chu *et al*., 2014; Hostetter, 2007, 2011). In the studies by Hostetter and Alibali, adults whose visuospatial skills were more advanced than their phonemic fluency were approximately 2.3 times more likely to use non-redundant gestures than adults whose skills were balanced or whose phonemic fluency was stronger than their visuospatial skills. This increased gesture use coupled with relatively stronger visuospatial skills could be indicative of a preference to communicate through the visual modality (Wagner *et al.*, 2014). Contrary to this finding, Chu *et al.* (2014) demonstrated that adults' visual working memory and mental transformation skills were negatively rather than positively correlated with iconic gesture frequency during a word definition task. Mental transformation entails manipulating a mental visual image, for example, in a paper folding task participants are presented with an image of a paper with dotted lines and they are asked to mentally fold the paper on the dotted lines and imagine the shape that the paper takes on. Hostetter and Alibali (2019) explained Chu *et al.*'s finding not through a preference for visual communication but rather through the cognitive benefits of using gestures. Specifically, they argued that individuals with low visuospatial skills were more inclined to use gestures because it helped them to mentally organise information. Consequently, evidence from adult studies points in both directions; adults with low rather than average visuospatial skills use more gestures due to cognitive benefits, and adults with high visuospatial skills use more gestures than adults with average skills due to a preference for the visual modality.

Spatial gestures & visuospatial skills

In studies that included participants with Williams syndrome, authors hypothesised about the role of visuospatial skills in gesturing only insofar that this affected spatial vocabulary skills (Bello *et al.*, 2004; Mastrogiuseppe and Lee, 2017). Consequently, these studies have specifically focused on the use of gestures that conveyed spatial content, for example, indicating with the index finger the path of a falling object. Whereas gesture-speech integration refers to the relation between gesture and speech, the content pertains to the meaning of the gesture rather than the extent to which this meaning is or is not represented in speech. Compared to mental-age matched participants, individuals with Williams syndrome not only produced a higher number of non-redundant gestures during a cartoon retell task but also a higher number of gestures that conveyed spatial content (Mastrogiuseppe and Lee, 2017). Mastrogiuseppe and Lee hypothesised that the impaired visuospatial skills affected vocabulary relating to spatial concepts, which resulted in a relatively higher use of spatial gestures, rather than gestures depicting actions or objects, compared to mental-age matched peers. Considering that the participants' vocabulary and visuospatial skills were not integrated in the analyses, further study is warranted.

As Chu *et al.* (2014) stated, correlational designs that include cognitive skill measures may give more insight into individual variability in gesture use. Due to diverging diagnostic criteria in studies that include participants with developmental language disorder and within-group variability (Bishop *et al.*, 2017), researchers should not immediately attribute group differences to language difficulties but rather should account for nonverbal skills in their analyses (Wray *et al.*, 2017) through correlational designs (Chu *et al.*, 2014). To this end, the present study focused on the use of supplementary gestures and spatial gestures in participant groups who differ considerably with respect to vocabulary and visuospatial skills: participants with typical development, participants with developmental language disorder, and participants with Williams syndrome. To achieve this, both this group distinction as well as the individual lexical and visuospatial skills were integrated in one statistical model.

Purpose

A first aim was to confirm the findings from earlier studies that participants with developmental language disorder and participants with Williams syndrome use a higher number of redundant gestures, complementary gestures, and supplementary gestures than their peers (Blake *et al.*, 2008; Lavelli and Majorano, 2016; Mainela-Arnold *et al.*, 2014; Mastrogiuseppe and Lee, 2017). A second research aim concerned disentangling the influence of vocabulary and visuospatial skills and their relative contribution to the use of supplementary gestures in the three participant groups. Because findings have been inconsistent on whether children with developmental language disorder do or do not use relatively more supplementary gestures compared to age-matched peers (Mainela-Arnold *et al.*, 2014; Wray *et al.*, 2017), the group distinction is examined as a factor. Lexical and visuospatial skills are integrated in the analyses to account for individual skills and potential within-group variability. A third research aim concerned the relation between visuospatial skills and the use of gestures with spatial content. It is expected that: (a) participants with Williams syndrome produce relatively more spatial gestures than participants with developmental language disorder or typical development (Mastrogiuseppe and Lee, 2017), and (b) that this increased rate is inversely related to their visuospatial skills. Because this influence may be moderated by vocabulary skills concerning spatial concepts (Mastrogiuseppe and Lee, 2017), our hypothesis is also explored for the subtype of supplementary gestures with spatial content. If a lack of knowledge in spatial vocabulary underlies increased gesturing, then we may expect this higher proportion of spatial gestures particularly in supplementary gestures.

METHODS

Research design and ethics statement

This study was a quasi-experimental, non-randomised cohort study. Gesture use during a narrative task was compared between participants with developmental language disorder and participants with typical development, and between participants with developmental language disorder and participants with Williams syndrome. The procedures have been reviewed and approved by the Research Ethics Committee UZ/KU Leuven (protocol number B322201835033). The children’s parents gave written informed consent and the participants gave oral assent. The present study is the second part of a larger study (see Rombouts, Maes and Zink, 2020, for the first part).

Participants

Twenty-five participants with developmental language disorder aged between 7;00 and 9;11 (years; months), 25 participants with typical development also aged between 7;00 and 9;11, and 14 participants with Williams syndrome who had moderate intellectual disabilities and were aged between 9;01 and 23;00 years (X = 13;11) entered the study. All participants were Dutch-speaking, and more specifically, Flemish Dutch. To recruit participants with developmental language disorder, speech-language therapists were contacted by telephone. Children qualified for the study when they had an official diagnosis of developmental language disorder. According to the national protocol, this diagnosis entails that children score extremely low (percentile ≤ 3) on one language aspect or low (percentile ≤ 10) on two language aspects. This language deficit is not caused by a psychiatric disorder, acquired neurological disorder, or motor disorder. A final diagnostic criterion is therapy resistance; children make limited progress after nine months of intensive language therapy. The criterion on therapy resistance was used because it echoes the poor prognosis of enduring language problems over the age of 5 in the Delphi consensus study by Bishop *et al.* (2017), and nine months was used specifically because it is a national criterion for the official diagnosis of developmental language disorder. Multilingual children were included because given our multicultural/multilingual society excluding these children threatened feasibility, and the developmental language disorder diagnosis entails that the observed language deficit is not the mere result of lower language exposure. Therapists handed out the informed consent to the parents of the children who qualified to enter the study. Children with typical development were recruited via schools. Linguistic skills of these children were not comprehensively assessed, but typical language development was assumed based on >25th percentile rank performance on the Active Vocabulary subtest of the Clinical Evaluation of Language Fundamentals-4-NL (CELF-4; Dutch version: Kort *et al.*, 2010) and no history of ever receiving language intervention services. Participants with Williams syndrome were recruited through the official organisation for parents of children with Williams syndrome. The syndrome was the only inclusion criterion. Because the prevalence of this syndrome is low, there were no exclusion criteria.

Matching participant groups

Twenty-five participants with typical development were recruited based on chronological age-matching with the participants who have developmental language disorder. To increase feasibility, we set ranges on what constitutes the same age. A child was considered the same age if the children belonged to the same normative range - the rationale being that their language skills should be comparable were it not for the presence of the disorder. This way, a child with typical development aged 7;01 did not have to be matched with a child with developmental language disorder aged 7;01 but could be matched with a child aged between 7;00 and 7;02.11. To still remain strict about the age, we chose the narrowest age range as provided by a standardised linguistic test: the age ranges from the Peabody Picture Vocabulary Test-III-NL normative tables (PPVT, Dutch version: Dunn and Dunn, 2005).

Due to the low prevalence of Williams syndrome, a priori matching did not occur, but rather matching was checked posthoc. In contrast to the matching of children with typical development and developmental language disorder, matching in participants with Williams syndrome was not based on chronological age because they had intellectual disabilities. The participants with Williams syndrome could only be matched with children with developmental language disorder and not with children with typical development. The skills of participants with Williams syndrome and developmental language disorder were matched on receptive vocabulary. A post-recruitment review revealed that the participants with developmental language disorder and Williams syndrome had similar scores on the PPVT which measures receptive vocabulary and has high correlations with verbal intelligence (Dunn and Dunn, 2005), $t(35) = -1.22$, $p = .232$, $X_{difference} = -4.46$, $SD = 3.67$, $95\%CI = [-11.92; 2.99]$. While the children with developmental language disorder scored similarly on the PPVT (X = 93.00, SD = 10.29) compared to the participants with Williams syndrome (X = 97.46, SD = 11.35), it should be noted that the PPVT is a verbal test and that the verbal skills of the latter group are relatively stronger than those of the former group. The significantly lower PPVT scores of the children with developmental language disorder (X = 93.00, SD = 10.29) compared to their peers with typical development (X = 115.44, SD = 10.22) likely indicate their language difficulties rather than a lower intelligence, $t(47) = 7.66$, $p < .001$, $X_{difference} = 22.44$, $SD = 2.93$, $95\%CI = [16.55; 28.33]$. Per report, the children with developmental language disorder did not have intellectual disabilities. They were recruited through special schools and classes that are specifically tailored to children with developmental language disorder that do not have intellectual disabilities. To this end, in the educational system all children will have been assessed with standardised IQ testing. Therefore, attendance of the child in the particular school (i.e. classes for children with developmental language disorder) indicated that he/she had IQ within the normal range.

Materials

A 4-min non-verbal animated film was shown to each participant (CGMeetup, 2017). This film contained sound effects and background music. The cartoon used in the present study was rich in spatial content, which may elicit more gestures and more spatial gestures in particular (Seyfeddinipur, 2012). The cartoon shows the story of a young man and woman who are in love. Three balconies are central to the story. The lovers stand on the outer balconies, and an older man is standing on the middle balcony. The young man sends several gifts to the woman across these balconies, much to the dismay of the older man on the middle balcony. The children's retellings of this cartoon were recorded on video and transcribed.

Participants' vocabulary skills and visuospatial skills were measured. Similar to earlier studies that focused on the relation between gestures and verbal skills in children with atypical development, expressive language skills were measured by assessing expressive vocabulary skills (Bello *et al.*, 2014; Wray *et al.*, 2017). In the present study, the Active Vocabulary subtest from the Clinical Evaluation of Language Fundamentals-4-NL was used (Kort *et al.*, 2010). Participants' visuospatial skills were assessed with the Perceptual Organization Index from the Wechsler Intelligence Scales-III-NL (Kort *et al.*, 2005). The index measures the ability to organise visuospatial information within a time limit and requires a visual-motor response. The between-group differences presented in Table 2 and the descriptive data in Table 3 align with the expected reverse strength-weakness profile of participants with developmental language disorder and Williams syndrome concerning their verbal skills and visuospatial skills. Specifically, children with developmental language disorder had significantly lower lexical skills compared to children with typical development and children/young people with Williams syndrome. Concerning visuospatial skills, the latter group scored significantly lower compared to children with developmental language disorder, which is in line with expectations given that visuospatial skills are particularly difficult for people with Williams syndrome (e.g., Berencsi *et al.*, 2016). Some children with developmental language disorder had low visuospatial skills (Bishop *et al.*, 2017; Wray *et al.*, 2017), yielding a significant group difference compared to the visuospatial skills of children with typical development.

Table 2. Group differences in expressive vocabulary and visuospatial raw test scores

Groups	*t*	*df*	*p*	*X*	*SD*	95% CI LL	95% CI UL
				Expressive Vocabulary			
TD-DLD	9.92	47	< .001	18.19	1.83	14.50	21.88
DLD-WS	-4.15	35	< .001	-10.87	2.62	-16.19	-5.55
				Visuospatial Skills			
TD-DLD	4.59	47	< .001	30.15	6.57	16.94	43.37
DLD-WS	3.22	35	.003	25.67	7.98	9.48	41.87

Note. TD = typically developing; DLD = developmental language disorder; WS = Williams syndrome; LL = lower limit; UL = upper limit.

Table 3. Descriptive data for expressive vocabulary and visuospatial raw test scores

Participant group	*X*	*SD*	*Min*	*Max*
		Expressive Vocabulary		
TD	41.40	5.94	29	50
DLD	23.21	6.88	12	41
WS	34.08	8.85	19	50
		Visuospatial Skills		
TD	107.36	23.11	75	151
DLD	77.21	22.85	36	118
WS	51.54	23.76	15	97

Note. TD = typically developing; DLD = developmental language disorder; WS = Williams syndrome.

Procedures

Data collection

The main researcher conducted the testing at the child's school in a separate room where only the child and researcher were present. Six adolescents/children with Williams syndrome and five children with typical development participated during school holidays, and so they were tested at their home in a separate room where only the main researcher and child were present. During testing, the participant and researcher sat opposite each other. The cartoon was shown to each individual participant via a laptop screen that sat on the researcher's lap and that was facing the participant. The cartoon was split into five excerpts to reduce memory effects. Aiming to ensure that each excerpt coincided with the completion of a plot element, the length of the five excerpts varied, as follows in chronological order: 39 sec, 26 sec, 54 sec, 1 min 18 sec, and 20 sec. After the participant had watched an excerpt, the researcher would say "Tell me what happened, I'm really curious". The researcher encouraged participants to tell everything they had seen by using expectant pauses and general prompts such as "Did anything else happen". Notably, this narrative task was administered alongside other experimental gesture tasks that are discussed in another study (Rombouts *et al.*, 2020). Because the present task was the first gesture task in that procedure – the full procedure has been described in Rombouts *et al.* (2020) , performance could not have been influenced by the other gesture tasks.

Data coding

The participants' retellings of the cartoon were transcribed. The first author delineated the clauses in the transcript. The following guidelines were upheld for utterance delineation: (a) each main clause, coordinated clause, and subordinate clause was counted as a separate clause, and (b) clauses did not have to be syntactically complete, and 1-word or 2-word utterances that stood on their own as denoted by falling intonation could also constitute a clause. After transcription, it appeared that all clauses observed in our study consisted of at least a subject and predicate. This predicate could also be achieved through gesture. For example, "And then he … (*mimics climbing*)", was considered as a clause. Children with typical development produced on average 45 clauses (ranging from 13 to 88; *SD* = 19), children with developmental language disorder also 45 (ranging from 22 to 71; *SD* = 14), and participants with Williams syndrome 31 clauses (ranging from 19 to 45; *SD* = 8).

Then, the first author coded the iconic gestures using two rubrics. The first rubric pertained to gesture-speech integration, which entailed a distinction between redundant, complementary, and supplementary gestures. Notably, supplementary gestures in our study could but did not need to co-occur with speech, as illustrated by the climbing-example above (Hsu, Brône and Feyaerts, 2021). The category of supplementary gestures included both pantomimes, i.e., gestures that did not co-occur with speech within the narrative (Marentette, Furman, Suvanto and Nicoladis, 2020) that were embedded in the linguistic structure, and co-speech gestures that depicted a non-essential constituent that was not expressed in speech (e.g, specifier, adverb). A second rubric was used to code the content of the gestures. Because the researchers had been trained in using a rubric that scored gesturing strategy this rubric was used to denote content. The rubric contained four categories or strategies to convey meaning: handle/enact, body-part-as object (BPO), draw/shape, and spatial. The handle/enact gesture involves mimicking the use of an object or a condition, for example a “toothbrush” or “being cold”. In the BPO gesture, the hand represents the object, for example forming a V-shape with the hand to denote “scissors”. In the draw/shape gesture, individuals draw or shape with their hands the outlines of the object, for example, a mirrored vertical curved motion with two cupped hands to indicate the shape of a ball. These three techniques are used to depict objects, actions, or conditions (Ortega and Özyürek, 2019). Objects, actions and conditions encompass the target items from, for example, the Boston Naming Task or the Active Vocabulary subtest from the CELF-4. The fourth type of gesture, the spatial gesture, is semantically light and denotes a path or direction without depicting the manner of movement (Cocks *et al.*, 2013). Gestures denoting a direction (e.g., abstract pointing to denote the location of the three balconies in the story), motion, or path (such as the erratic path of the bird flying around when attacked) were regarded given that they “bear a close relationship to the semantic content of speech” (McNeill, 1992, p. 12). Nevertheless, we recognise that spatial gestures are semantically lighter than iconic gestures that depict objects or actions. While this strategy rubric has an indirect relation to content, for example gesturing “scissors” may be achieved through different strategies, this does not constitute a problem for the present study because we only focus on spatial gestures in this study. The spatial category has a clear and direct relation to the gesture’s content. The first author coded all gestures, and a research assistant independently coded 72.82% (626/861) of gestures. Reliability was strong; the Cohen kappa agreement for the gesture-speech integration was .812 (88% agreement) and Cohen Kappa agreement for strategy/content .872 (90% agreement).

Data analysis

Gesture-speech integration

For the first research aim, three gesture-clause rates were calculated: the rate of redundant gestures per clause, the rate of complementary gestures per clause, and the rate of supplementary gestures per clause. While some studies calculated a gesture-word rate (e.g., Mainela-Arnold *et al.*, 2014), we used a gesture-clause rate similar to Mastrogiuseppe and Lee (2017) or Colletta, Pellenq and Guidetti (2010). Children with language disorder may use more telegraphic speech, for example, containing fewer function words (e.g., Leonard, 2009). Because the use of gestures has been found to correlate with the length of a narrative but not with narrative complexity nor with function words (Nicoladis, Marentette and Navarro, 2016), we opted to use a clause rather than word to represent a unit of meaning.

One-factor between-group comparisons were conducted with the three gesture-clause rates. Each of these gesture-clause rates was compared between individuals with developmental language disorder and typical development and between participants with developmental language disorder and Williams syndrome. Visual examination of Q-Q plots and Shapiro-Wilk testing showed that data did not have a normal distribution, between-group comparisons were performed with Mann Whitney *U* testing.

Supplementary gestures, lexical skills, & visuospatial skills

Within the second aim, we examined the rate of supplementary gestures relative to the overall gesture use in relation to the group factor, vocabulary skills, and visuospatial skills. Because participants belonging to a particular group may show heterogeneous expressive vocabulary and visuospatial skills and given that these skills may shape gesturing, analyses not only included the group factor but also the visuospatial and expressive language skills. To this end, we conducted Poisson generalised linear models. In these models, the absolute number of supplementary gestures represented the dependent variable and the total gesture use was included as offset variable (Mainela-Arnold *et al.*, 2014). Models were built stepwise by sequentially including the following factors: group, expressive vocabulary skills, and visuospatial skills. This sequence was informed by the results from Wray *et al.* (2017). For the vocabulary and visuospatial skills, raw scores were used. The best fitting model was selected by considering the factors' significance values and comparing the Bayesian Information Criterion (BIC) between the models. A lower BIC-value indicates a better fit, and following Raftery (1995), a difference in BIC-values of 0-2 is considered weak, 4-6 positive, 6-10 strong, and > 10 very strong. The participants with developmental language disorder represented the reference group because, similar to the one-factor between-group comparisons, their scores were compared with the two other participant groups.

Gesture content & visuospatial skills

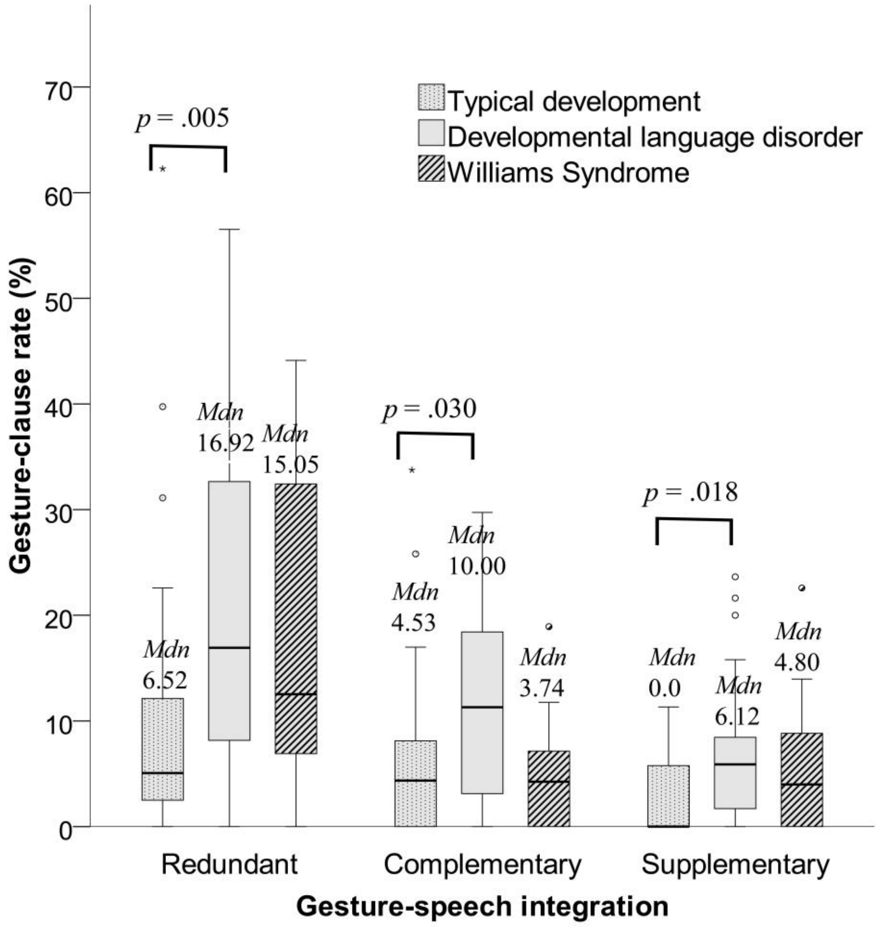
To investigate the rate of spatial gestures in relation to the group distinction and visuospatial skills, we also aimed to use Poisson modeling. Nevertheless, because this variable's residuals did not follow a Poisson distribution, we split the analysis into two separate tests. First, we examined a between-group difference in the relative use of spatial gestures by conducting a ranked ANCOVA. A ranked ANCOVA involves ranking the dependent variable and the covariate, obtaining the residual of the ranked dependent variable in relation to the ranked covariate, and finally running a one-factor ANOVA with this residual (Quade, 1967). In this ANCOVA, the number of spatial gestures was the dependent variable, the group distinction constituted the factor, and the overall gesture use was the covariate. To gauge the relation between the spatial gesture rate and visuospatial skills, we then conducted partial rank order correlations between the number of spatial gestures, raw expressive vocabulary scores, and raw visuospatial skills scores while controlling for overall gesture use.

RESULTS

Gesture-speech integration

As illustrated in figure 1, the total gesture-clause rate of participants with developmental language disorder was significantly higher than the gesture-clause rate of participants with typical development, $U = 179.00$, $p = .010$, $r = .472$, $95\%CI = [.204; .674]$. The former participants produced significantly more redundant gestures, $U = 169.50$, $p = .005$, $r = .490$, $95\%CI = [.226; .687]$, complementary gestures, $U = 201.50$, $p = .030$, $r = .378$, $95\%CI = [.091; .607]$, and supplementary gestures per clause, $U = 193.00$, $p = .018$, $r = .384$, $95\%CI = [.098; .611]$. Participants with developmental language disorder and Williams syndrome did not differ in overall gesture rate, $U = 130.00$, $p = .329$, nor in the rate of redundant, $U = 135.50$, $p = .411$, complementary, $U = 101.50$, $p = .060$, and supplementary gestures per clause, $U = 138.50$, $p = .465$.

Figure 1. Gesture-clause rates for each participant group.



Supplementary gestures, lexical skills, & visuospatial skills

A model containing only the group factor was not significant, $X^2(2) = 1.15$, $p = .469$, $BIC = 198.22$. Including expressive vocabulary yielded a significant model, $X^2(3) = 12.19$, $p = .007$, $BIC = 184.78$, whereas including visuospatial skills did not result in an improved model, $X^2(4) = 12.67$, $p = .013$, $BIC = 188.25$. A model that included only expressive vocabulary skills generated the best fit, $X^2(1) = 6.48$, $p = .011$, $BIC = 182.53$, and represented a strong improvement over the group-only model and a weak to moderate improvement over the model containing the factors group, visuospatial skills, and expressive vocabulary. Per point decrease in the expressive vocabulary raw score, participants were 1.9% more likely to produce supplementary gestures, 95% confidence interval = [0.4%; 3.4%].

Gesture content & visuospatial skills

A Ranked ANCOVA on the number of spatial gestures relative to the overall gesture use revealed no between-group difference, F(2, 60) = .502, p = .562. Similarly, when examining whether the use of spatial gestures may specifically differ within the subtype of supplementary gestures, no between-group difference was found, F(2, 60) = .585, p = .560. Supplementary gestures conveyed spatial content in 55.26% (21/38), 38.82% (33/85), and 42.31% (11/26) of all gestures in participants with typical development, language disorder, and Williams syndrome respectively. Of all spatial gestures, gestures replaced speech for participants with typical development, developmental language disorder, and Williams syndrome in in 18.75% (21/112), 16.50% (33/200), and 20.37% (11/54) respectively. The correlation between spatial gestures and visuospatial skills while controlling for overall gesture use was not significant when all participant data were combined, r_s = -.008, p = .978, nor when only the data from participants with Williams syndrome were considered, r_s = -.200, p = .534.

DISCUSSION

Iconic gestures are instrumental in language acquisition, and therefore, the use of iconic gestures in children with atypical language development has been widely studied. While studies have shown that children with developmental language disorder and children with William syndrome frequently use supplementary gestures (Blake *et al.*, 2008; Lavelli and Majorano, 2016; Mainela-Arnold *et al.*, 2014; Mastrogiuseppe and Lee, 2017), it is unclear whether their use of supplementary gestures is also proportionally higher compared to peers with typical development. Particularly concerning children with developmental language disorder, findings on the gesture-speech integration of iconic gestures diverge (Mainela-Arnold *et al.*, 2014; Wray *et al.*, 2017). Given that children are heterogeneous, our aim was to analyse gesture-speech integration of iconic gestures starting not only from a categorical distinction between groups of children but also from an individual skill level. Following the results from studies in adults with typical development (e.g., Chu *et al.*, 2014; Hostetter and Alibali, 2007, 2011, 2019), the present study focused on the relation between gesture-speech integration of iconic gestures, lexical skills, and visuospatial skills in children groups with different strength-weakness profiles: children with typical development, developmental language disorder, and Williams Syndrome. We hypothesised that lower lexical skills were associated with a proportionally higher use of supplementary gestures and that lower visuospatial skills were associated with proportionally higher use of (supplementary) spatial gestures.

Gesture-speech integration

As expected, gesture rates were higher in participants with developmental language disorder compared to participants with typical development, and they were similar to the gesture rates of participants with Williams syndrome (Bello *et al.*, 2004; Mainela-Arnold *et al.*, 2014; Mastrogiuseppe and Lee, 2017; Wray *et al.*, 2017). However, supporting Mainela-Arnold *et al.* (2014), a model containing the group factor was not significant, which indicates that all groups were similarly likely to use supplementary gestures relative to their overall gesture use. Wray *et al.* (2017) argued that the 90-sec animation film used in Mainela-Arnold *et al.* (2014) was too easy to affect the difference in gesture-speech integration between participants with typical development and developmental language disorder. Even though the present cartoon had a similar length because it was presented to each participant in five excerpts, it was probably more difficult. Participants found it sometimes hard to indicate whether they were talking about the young man or the old man. In addition, the cartoon contained abstract features, such as kisses flying in the shape of little hearts, and low-frequency objects such as a flower wreath. Even though the present cartoon was probably more difficult compared to the cartoon in Mainela-Arnold *et al.*, both studies found no between-group differences in the relative use of supplementary gestures. Nevertheless, the absence of significant between-group differences may be explained by the heterogeneity of the groups, indicating the need to include individual skills in the analyses.

Supplementary gestures, vocabulary skills, & visuospatial skills

Indeed, the model that best predicted the relative supplementary gesture rate contained only the expressive vocabulary scores. This result together with the observed high intra-group variability in language and visuospatial skills, which was also observed in Wray *et al.* (2017), indicates that it may be misleading to explain between-group results in the context of language and cognitive skills. Participants with developmental language disorder are not likely to be a uniform group because their language, motor, visuospatial skills may vary (Bishop *et al.*, 2017). Therefore, speech-integration should be studied in relation to specific skills, in this case expressive vocabulary, rather than a diagnosis. This may also shed light on why children with developmental language disorder used more supplementary gestures during more complex rather than easier descriptive tasks in Wray *et al.*'s study (2017). The present finding that vocabulary skills shape supplementary gestures aligns with the hypothesis proposed by those authors that higher language and cognitive demands resulted in fewer resources for language processing and, therefore, higher gesture use. Our findings demonstrate that vocabulary skills are an important factor in the use of supplementary gestures, regardless of neurodevelopmental condition or typical development. Whether the vocabulary skills are a relative strength or weakness in the individual’s cognitive profile did not influence gesture use, but rather the advancement of the skill itself was influential. Similar to Wray *et al.* (2017), the proportional reliance on supplementary gestures may be particularly high in children with severe lexical deficit, given that in our study scoring one raw score fewer on the Active Vocabulary Subtest coincided with a 1.9% increase in supplementary gestures.

Nevertheless, language and processing difficulties are more diverse than lexical retrieval. Because other language subtests were not included, the role of other linguistic abilities such as morphosyntax could not be examined. The dysfluencies that Alibali *et al.* (2009) coded and examined in relation to children’s use of non-redundant gestures were not limited to explicit word-finding difficulties and included dysfluencies that likely relied on morphosyntactical skills. It is possible that children with lower vocabulary skills may also score lower on other linguistic measures. In addition, it is important to note that adults’ phonemic fluency and not semantic fluency was related to gesturing rate in a study by Hostetter and Alibali (2007). These authors argued that phonemic rather than semantic fluency is more related to executive control and structuring information, while semantic fluency measures the efficiency of lexical access. Perhaps, organizing and structuring information rather than vocabulary skills underlies an increased reliance on supplementary gestures. Only by including various different language subtests can we gain further insight into this matter.

Supplementary gestures allow the child to express more complex utterances compared to verbal-only utterances, and future research may focus more on the effectiveness of implicit gesture modeling in bolstering the child’s gesturing, word acquisition, and language production complexity. Encouraging children to use co-speech gestures and non-co-speech gestures may facilitate their word acquisition and overall language production. The association between lexical skills and iconic gesture use is supported by the demonstrated effects of implicit modeling on word learning. In Vogt and Kauschke’s studies (2017a, 2017b), a researcher implicitly modeled iconic gestures while telling a story to children with developmental language disorder and typically developing children. The authors observed in both groups that iconic gestures aided naming and semantic processing significantly more than attention-drawing gestures such as a raised finger. It remains to be studied to what extent children align to (i.e., adopt) the gestures implicitly modeled by their interlocutors. Such alignment may support language complexity as gestures can fulfill constituents that are not expressed in speech. Indeed, the use of non-co-speech gestures (or pantomimes) may support narrative development given that 8 to 11-year-olds with typical development who used these gestures produced longer narratives with similar or higher quality than children who used no or few pantomimes (Marentette *et al.*, 2020). Finally, there is environmental input to consider; research in young children with atypical development showed that parents labeled the non-co-speech gestures used by their child, which supported their child's word acquisition (Dimitrova *et al.*, 2016).

Similar to Wray *et al.* (2017), regression modeling showed that visuospatial skills did not influence the rate of supplementary gestures. While this does not align with Hostetter and Alibali (2007) and Chu *et al.* (2014), it should be noted that these studies were conducted in an adult population with typical development and focused exclusively on the overall gesture rate. Because of the specific nature of supplementary gestures, the association with vocabulary skills may have been significantly larger than the influence from visuospatial skills. Furthermore, the association between supplementary gestures and lexical skills may be larger for children than adults (Alibali *et al.*, 2009). As Alibali *et al.* (2009) argued, the use of non-redundant gestures may differ between children and adults due to diverging verbal skills. Consequently, findings on the role of visuospatial skills from studies with adults may also not apply to children. The function of the gesture may change throughout the child's development while it evolves from lexical fillers to adding rich, multimodal information to narratives (Capone and McGregor, 2004; Colletta *et al.*, 2010) and, potentially, the relation to different cognitive skills too may alter. Given that in the present study visuospatial skills did not shape gesture use and that a significant inter-relation (albeit not clearly defined relation) was found in studies with adults (Chu *et al.*, 2014; Hostetter and Alibali, 2007, 2011), perhaps at an early age verbal skill primarily shapes gesture use, and only when language development is near complete, do visuospatial skills shape gesturing rate too. However, given the contradictory findings concerning the relation between gesture use and visuospatial skills in adults (Chu *et al.*, 2014; Hostetter and Alibali, 2007, 2011) and limited studies in children that included these skills, no clear conclusion may be drawn concerning a differential role for visuospatial skills in gesture use from childhood to adulthood. To gain insight into this role of visuospatial skills, future cross-sectional studies should include more age groups, ranging from childhood to adulthood.

Spatial gestures & visuospatial skills

In contrast to lexical skills, visuospatial skills did not influence the use of supplementary spatial gestures as all participant groups were equally likely to use spatial gestures. In addition, the use of spatial gestures did not correlate with visuospatial skills. While this finding is not consistent with the results from Mastrogiuseppe and Lee (2017), two differences between our studies may explain the diverging results. First, we opted to focus on supplementary spatial gestures due to the hypothesised link between supplementary gestures and vocabulary. Second, Mastrogiuseppe and Lee's proposed hypothesis (2017) primarily concerned visuospatial vocabulary, but this was not measured in the present study. Therefore, it remains possible that participants with lower visuospatial vocabulary were more inclined to use spatial gestures than participants with higher visuospatial vocabulary.

Limitations and future directions

Some methodological issues need to be noted. First, due to the rare prevalence of Williams syndrome, it was not possible to match these children at an individual level. While their PPVT-scores at group level did not significantly differ from the children with developmental language disorder and comparisons were made at group level, variability within the group could still have affected our results. By including the individual visuospatial and expressive vocabulary skills within the statistical model, we aimed to account for variability. Another potential source of variability was the inclusion of multilingual children, who had a higher representation in the group of children with developmental language disorder than in the other two groups. Even though the diagnosis entails that the language deficit is not (merely) caused by low language exposure (Bishop *et al.*, 2017), differences in language exposure could have impacted on the Active Vocabulary test scores. While we believe that this did not pose an issue to the validity of our findings given that we examined gesture use during a Dutch-speaking task in the context of Dutch expressive vocabulary proficiency, it is important to have a comprehensive view on our participants' background and linguistic profiles. Therefore, we advise to include a language exposure measure in future studies.

It should also be noted that the rather artificial nature of the task may have had an impact on the participants' spontaneity and use of spontaneous gestures. Participants told the story to the main researcher, and some participants probably figured out that the researcher already knew the story, which lowered the need for gestures that benefit the listener. Anecdotally, one participant with Williams syndrome did not produce a single gesture during the narrative task, but immediately after the testing had ended, he enthusiastically told the story to his parents in the next room while using iconic gestures. In future studies, including a naive listener to whom the participants tell the story can enhance the ecological validity of the task and render a more accurate representation of spontaneous gesture use.

While the present study provides insight into the skills that are associated with gesture-speech integration, understanding the mechanism of how gestures facilitate language production (e.g., relieving working memory load and/or increasing linguistic complexity) and how this facilitative effect relates to cognitive skills requires experimental task manipulations. Promising research for understanding this mechanism include manipulating the possibility for children to use gestures or interfering with specific cognitive processes during the task (Chu *et al.*, 2014) as well as combining a gradual increase in task complexity (Wray *et al.*, 2017) with linguistic analysis of gesture use during dysfluencies such as filled pauses, repairs, repetitions, or revisions (Alibali *et al.*, 2009). Because in the present study gesture use was not compared between fluent and dysfluent speech as it was in Alibali *et al.* (2009), no claims can be made concerning the potential compensatory function of gestures. Because quantitative studies offer an abstraction of complex natural language data, a mixed methods sequential explanatory design may be warranted to study the function or facilitative effect of gestures (Ivankova *et al.*, 2006). In such a design, a quantitative research phase, such as in the present study, is followed by a qualitative analysis phase aiming to give full understanding of the quantitative results. The consecutive order of these two research stages allows to start from the quantitative data to identify the focus of the qualitative analysis, for example unexpected results or outlier data. Consequently, this design can both detect group results or identify factors and then during the qualitative phase, for example through qualitative linguistic analysis methods, provide insight into how and when gestures are implemented as a communication support.

CONCLUSION

Supplementary gestures are an inherent part of speech and language development. While visuospatial skills rather than vocabulary skills shape gesture use in adults, the present study showed that children’s use of supplementary gestures was shaped by their vocabulary skills. This effect was found regardless of (a)typical development and diagnosis. Participants who experienced lower expressive vocabulary skills relied more strongly on supplementary gestures than children with higher skills. With these gestures, they fulfilled constituents they did not express in speech and thus achieved higher linguistic complexity. Combining experimental task manipulations with comprehensive assessments to examine the role of morphosyntax and the language-motor relation in the context of gesturing may give more insight into how gestures facilitate language production. Furthermore, future research into how the use of supplementary gestures may be encouraged is warranted, given that various children with language difficulties did not use them even though it may be a helpful strategy for children with lexical difficulties to achieve more complex expression. Understanding how gestures can bolster language production in children with atypical development and how gesture use may be encouraged is a first step in optimizing gesture interventions in these populations.

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