Individual differences in language development: Relationship with motor skill at 21 months

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Abstract

Language development has long been associated with motor development, particularly manual gesture. We examined a variety of motor abilities – manual gesture including symbolic, meaningless, and sequential memory, oral motor control, gross and fine motor control – in 129 children aged 21 months. Language abilities were assessed and cognitive and socio-economic measures controlled for. Oral motor control was strongly associated with language production (vocabulary and sentence complexity), with some contribution from symbolic abilities. Language comprehension however was associated with cognitive and socio-economic measures. We conclude that symbolic, working memory, and mirror neuron accounts of language-motor control links are limited, but that a common neural and motor substrate for nonverbal and verbal oral movements may drive the motor-language association.

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In adults and children, including in typically developing children and neurotypical adults as well as in atypical development and in language breakdown, links have been observed between motor functioning and language. Specifically, very strong links in all of these populations have been observed between gesture and language, and a common neural basis seems to link these abilities (Bates & Dick, 2002). It has also been suggested that this link may provide a clue to the evolutionary precursors of human language (Arbib, 2005).

Examining the motor bases of early language development may also provide us with information about the origins of language development difficulties, particularly Specific Language Impairment (SLI) (Bishop, 2002; Hill & Bishop, 1998), as well as language functioning in other developmental disabilities such as autism, where language abilities are highly variable and seem to depend to some extent on children's motor abilities (Gernsbacher, Sauer, Geye, Schweigert, & Hill Goldsmith, 2008). Knowing more about the origins of language acquisition, particularly the associations between non-linguistic abilities and language development, may also enable us to discover more about why some children develop language much more rapidly than others (Fenson, Dale, Reznick, & Bates, 1994).

Motor-language relationships in development

The links between some types of motor development, in particular gesture development, and language development, are widely noted (Bates, 1980; Bates & Dick, 2002; Goodwyn, Acredolo, & Brown, 2000; Iverson & Thelen, 1999; Meier & Willerman, 1995; Thal & Tobias, 1994). However, links between motor and typical language development do not appear to extend to all types of motor development – in particular there does not appear to be a strong link between language development and gross motor development (Bates, 1979; Bonvillian, Orlansky, & Novack, 1983). Various theories seek to explain this association between manual gesture and language in development. We will now examine some of these relevant theories.

Symbolism, gesture and language.

Some researchers suggest what gesture and language have in common is the symbolic nature of both. Bates et al. (1989) examined the link between children's production of familiar object gestures (gestural depiction) and their language abilities, and found that while language comprehension mediated between children's gesture and language production, there was also some evidence for a common developmental path for both types of production, which may be due to a symbolic component in both. Motor and language abilities appear to reach common milestones – such as repetitive action, symbolic use, and combinatorial use – on the same schedule (Bates & Dick, 2002).

Mirror neuron theory

The discovery in primates of mirror neurons – neurons that respond both to action and to the observation of action (Rizzolatti & Arbib, 1998) – has led to new ideas about a mechanism linking gesture and language. Arbib (2005) suggests that mirror neurons may offer an explanation for the evolution of language, and its potential origin in gestural systems of communication. It is suggested that Broca's area evolved from a mirror system for grasping, which can both generate and recognise actions. Premotor neurons are involved in planning actions and these areas have been shown using fMRI to respond to auditory stimuli (Wilson, Saygin, Sereno, & Iacoboni, 2004), and in primates mirror neurons appear to code for both auditory perception and motor actions, without any coding for sound production (Kohler et al., 2002). This direct motor-auditory perception link could enable abstract neural representations of motor control and speech input together, and could explain the link between speech representation and manual gesture representation. Since mirror neurons respond to both perception of a movement and production of a similar movement, these may be the substrate for links between movement (either limb or mouth) execution and perception of related movements – including links between movement execution and perception of speech.

The role of working memory in motor control and language

Klapp (2003) suggests that production of speech involves both selection of individual movements necessary for a particular speech act and the integration of the sequence of these movements. Extensive research (Gathercole, 2006) backs up the idea that working memory is an important skill for language acquisition. Most such research focuses on phonological working memory, testing this by asking children or adults to repeat unfamiliar sequences of syllables or pseudowords, but it is possible that a crucial aspect of this ability for language is the motor sequencing ability, as well as or instead of the phonological analysis aspect of phonological working memory.

Embodied cognition, motor and language processing

The embodied cognition perspective suggests that thought is influenced by action, including influences of action on language. For example, seeing or hearing the name of an object of differing size, or words denoting size, leads to differing speed of response depending on the size of grip required (Fischer & Zwaan, 2008). This theory predicts strong motor-language links in development: language for a concept or object may become more available once an infant has enacted the concept or manipulated the object, or alternatively, once a lexical representation for an action or object has developed, this could drive easier access to the action or easier manipulation of the object.

Oral motor control and language development

Most research into motor/language links in development has concentrated on manual gesture. However, most mature language users communicate primarily using their mouths. Despite this bias in previous studies, there is some research indicating that a link exists between speech and language development and oral motor development. MacNeilage and colleagues (MacNeilage & Davis, 1993; MacNeilage, Davis, & Matyear, 1997) have examined pre-speech babble and have found that babble and speech tend to share similar motor patterns, those that are simple for infants. Infants tend to have a single articulatory framework within which they can vary the extent of their movements, without movement within the syllable, leading to different but related babble sounds in one infant, and with the V and C of one babble syllable being articulated in the same place. Ease of motor control also seems to drive the types of sounds available to infants, with labials dominating, possibly due to the need only to move the mandible, not the tongue. Oller, Eilers, Neal, & Schwartz (1999) found that late onset of babbling was associated with delayed language use up to 30 months. These two sets of data show the correlation between early phonetic and lexical abilities and babbling; both of these aspects of language are in addition highly predictive of children's later syntactic abilities (Bates & Goodman, 1999; Kuhl, Conboy, Padden, Nelson, & Pruitt, 2005), to the extent that some authors consider the lexicon and syntax to be aspects of the same system (Bates & Goodman, 1997).

Moore and Ruark (1996; Ruark & Moore, 1997) in contrast suggest that pre-speech movements are not related to babble and speech. They examined coordination in chewing and sucking and found this was not related to coordination in speech or babble movements: although MacNeilage's data (see above) examine babble, it is possible that two types of non-speech oral movements exist: those that are linked to chewing and sucking, but not to babble and speech, and those that are linked to babble.

Some evidence also links oral motor control with delayed speech and language. Qvarnstrom and colleagues (Qvarnstrom, Jaroma, & Laine, 1993, 1994) found that lip muscle tone and tongue coordination were related to articulation abilities up to the ages of 7 to 10 years, and children's abilities in oral motor control continued to improve in this age range. Pahkala, Laine, & Narhi (1995) made similar findings, and suggested that for some children immature articulatory patterns become fixed and habitual.

Children with developmental speech and language difficulties – primarily those with developmental verbal dyspraxia – have been found to have difficulties with oral motor control in addition (Alcock, Passingham, Watkins, & Vargha-Khadem, 2000; Dewey, 1993; Dewey & Kaplan, 1992; Dewey, Roy, Square-Storer, & Hayden, 1988; Vargha-Khadem et al., 1998). However, most studies of children's maturing oral motor control have either examined oral motor control in older children with speech and language difficulties, or have looked at typical development but in much younger, preverbal children (MacNeilage & Davis, 1993; MacNeilage et al., 1997). It is possible that speech, language and oral motor control might be disordered in the same children, but that no association between these abilities might be found in typically developing children with emerging language, especially once a certain level has been reached in their language ability. Babble may be related to typical oral motor abilities and very early speech articulation, but not production of spoken words and language in young verbal children. We investigate here links between spoken language abilities once children's speech is established and developing rapidly, and oral motor abilities.

Although it is obvious that most language users articulate with their mouths, and therefore fine non-verbal oral motor control may be necessary for good spoken language, it is also possible that baseline oral motor control is established early and does not limit spoken language abilities, but that a link may be found for another reason. This may be an indirect link through gesture. Alternatively it may be a link due to close, but not identical, neural representation; this argument is not quite the same as an argument based on common motor control. Spoken language may not rely on oral motor control but both spoken language and oral motor control may rely on adjacent neural areas, which develop in parallel, ending up well or poorly organised in the same individuals.

The representation of oral motor and manual gesture control in the cerebral cortex is very closely linked, as primate studies have shown (Rizzolatti et al., 1988). The areas that control both types of movement are also those found to recognise actions – the mirror neurons (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996). It is possible that the link between manual gesture and language is due to this common neural representation of oral motor and manual gesture control, so oral motor is linked to spoken language through the need for precise oral motor control in speech articulation, and manual gesture is then indirectly linked to spoken language through its co-localisation with oral motor abilities in the cortex.

Gross and fine motor control and language development

Gross and fine motor control are usually defined as the ability to make large limb movements or fine hand movements, respectively, with the latter often requiring detailed object manipulation, as distinct from gestural abilities that can be assessed without any manipulated object, or with more general movements relating to or symbolising the use of an object. Although early studies suggested that gross and fine motor development were closely linked to language development (Shirley, 1933a, 1933b), later work found that these were not as closely linked (Bates, 1979; Bonvillian et al., 1983). Links are found in some studies with atypical language development (Hill, 2001; Viholainen et al., 2006), but other studies find no such links: indeed early research by Bates and colleagues (1979) appeared to show that a correlation ran in the opposite direction. It is possible that this might still fit with Shirley's (Shirley, 1933a, 1933b) suggestion that a burst of development in motor abilities may occur at a time of a hiatus in language progression.

In contrast to work with typically developing children, however, there is a body of literature suggesting that children with language delay and disorders have both gross and fine motor impairments (Hill, 2001). Although the focus of this paper is on variation within the typically developing population, it is helpful to examine in addition abilities that may be impaired in children whose language is not developing in a typical manner.

Other factors associated with language development

Language development has however also been shown to be related to other non-linguistic abilities and factors. Cognitive development, particularly symbolic abilities (Hayiou-Thomas, Harlaar, Dale, & Plomin, 2006; Kelly & Dale, 1989; Lewis, Boucher, Lupton, & Watson, 2000), and family and parental factors such as socio-economic status (SES) and parental education (Hoff, 2006; Petrill, Pike, Tom, & Plomin, 2004; Schuele, 2001) are all known to be associated with individual differences in language development. In order to ensure that any differences we observe are not due to, for example, cognitively more advanced children also performing better on motor tasks, we will control for both cognitive abilities and family SES/education factors.

Here we set out to examine the relationships between motor abilities (including all of manual gesture, gross and fine motor control, and oral motor abilities) and language abilities in children around the time of the vocabulary burst – the point in language development at which the rate of change is theoretically fastest, leading to maximal individual differences. We predict that both manual gesture and oral motor abilities will be related to language abilities at this age. Although it is possible that manual gesture is only linked to language development because of the links of both of these abilities to oral motor abilities – manual gesture due to adjacent neural localisation and speech due to the necessity for good oral motor control in order to produce speech sounds – we predict that these relationships will be independent of each other, and independent of any relationships of cognitive abilities or parental/SES factors to language ability. Previous studies have examined gesture alone, without assessing oral motor control ability, a crucial aspect of motor control that is likely to be independently linked to language development.

If mirror neurons are the main reason for a language-motor control link, it can be predicted that relationships between manual gesture and language comprehension will be stronger than those with language production, since mirror neurons appear to link auditory perception to actions without relying on production of sound as an intermediary (Kohler et al., 2002). In order to examine different theories of motor/language links in development, we will however examine all of symbolic/object-related manual gesture, imitation of meaningless manual gesture, and gesture sequencing. We further predict that neither gross or fine motor development will be related to language ability.

Methods

Participant recruitment and allocation

A total of 129 children participated in some testing or their parents completed some questionnaires relating to their language and motor abilities. Briefly, families were recruited at children's birth through the maternity unit at the local hospital, and were contacted again when children were aged 18 months and asked if they wished to participate in the current study. At this age parents completed a short, 100 word version of the British adaptation of the McArthur-Bates Communicative Development Inventory (Fenson et al., 1994; Hamilton, Plunkett, & Schafer, 2000) and on the basis of this, children were divided into testing groups in such a way as to ensure even gender and initial language ability representation in three groups: a Motor group, who underwent laboratory testing in motor abilities (N = 31), a Combined Tests group, who underwent laboratory testing in oral motor abilities (as well as other, non-motor abilities; N = 35) and a larger Other group (N = 63).

Children in the Motor group were tested in the laboratory on all tests of motor control while children in the Combined Tests group were tested in the laboratory on only the oral motor test (see below). Parents of children in the Combined Tests group and the Other group completed questionnaires which assessed their gross and fine motor abilities and their manual gesture abilities (also described below). Parents of all children completed questionnaires assessing language and cognitive abilities (again, described below), and were interviewed to obtain information about SES and parental education. Children in the Other group also underwent additional laboratory testing in two categories (reported elsewhere: Alcock & Krawczyk, 2008; Alcock & Krawczyk, 2009), so the groups were initially designed as four equally-sized and equally representative groups (Motor, Combined Tests, Other A and Other B), but due to dropout final group size was slightly unequal.

Assessments: laboratory testing and parent- completed questionnaires

Tests of motor control

Manual gesture: Gesture "naming". To assess symbolic gesture, children were given 10 common objects in turn (such as a toothbrush or a book), and scored on the accuracy and independence of their attempts to demonstrate correct use of the object. Children were first presented with the item and asked to show the tester what they do with the item; this prompt was repeated once, and if children did not respond after two prompts, the tester modelled use of the object and then prompted the child again. Children were given 2 points per item correctly demonstrated or 1 point if the demonstration was inadequate, or only followed the tester's demonstration. This type of task or behaviour in children has previously been termed "gesture naming" or "gestural naming", as it appears to be analogous to verbal labelling of items (Bates et al., 1989; Tsuji, 2002). The score given to a child was the total number of points for each item (maximum 20).

Manual gesture: Meaningless gesture imitation. The tester demonstrated 10 simple meaningless gestures (such as knocking two fists together or knocking on the table with flat hands) in turn and encouraged the child to copy. Children were given 2 points for a correct imitation and 1 point for an attempt which reasonably approximated the target and totals were calculated as for gesture naming.

Manual gesture: Gesture memory. The tester used one of two sets of props (a doll and accessories, and a toy tool kit) to demonstrate four action sequences from two to six items in length. Children were asked to repeat the action sequence and were allowed assistance with individual actions (e.g. fastening the doll's bib) if dexterity limited a clearly intended action. Children were given a score of the number of items repeated in the correct order; for example, in the three-item sequence, if the first and third items were repeated but the second was incorrect or omitted, the child was awarded 2 points.

Oral motor ability: Single movement imitation. The tester demonstrated and described 10 single oral movements and encouraged the child to imitate. Two of the movements involved imitating the tester's face alone while props (either a puppet to be imitated, or appropriate toys such as a pot of bubbles to blow) were used for the remaining movements. Four movements were classed as "simple" (involving only one set of orofacial muscles – example: spreading lips wide as in smiling, requiring symmetrical movement of paired risorius muscles) and six as "complex" (involving more than one set of facial muscles – example: blowing bubbles, involving both lip rounding with the orbicularis oris, and aspiration). Children were awarded two points for a correct imitation of the movement and one for an attempt which either included only some elements of the movement or was limited in extent.

Oral motor ability: Speeded movements. The tester demonstrated three sets of rapid, repeated oral movements and one set of rapid alternating movements (open mouth, protrude tongue, close mouth). Children were encouraged to imitate each set of movements as rapidly as possible and the number of movements in 10 seconds was scored and averaged across movements.

All of the manual gesture and oral motor tests were videoed using a digital video camera and were scored after the testing session had ended. Timed movements were scored using the frame-by-frame facility of a digital video editor. Tapes from 20% of participants were double rated by a second observer and agreement for each subtest exceeded 90%. Internal consistency (Cronbach's alpha) was calculated for single oral movement imitation (.73) and the gesture scale overall (.61).

Gross and fine motor skills. Gross and fine motor skills were assessed using the Bayley Scales of Infant Development (BSID - Motor) (Bayley, 1993). For children of this age, typical items assessing gross motor development include climbing a small set of steps and standing on one foot; items assessing fine motor development include manipulating small pellets and pencil grip. Raw totals were calculated from the number of gross and fine motor items passed by each child.

Questionnaires

Language questionnaire. The Oxford CDI (Hamilton et al., 2000) was completed by parents in its entirety, with the addition of questions about word combining and grammatical usage taken from the MacArthur-Bates CDI (Fenson et al., 1994). In addition, the "Understands" and "Understands and says" columns were retained, giving separate totals for words comprehended and words produced. This questionnaire hence yields three scores: CDI – Production; CDI – Comprehension and CDI – Complexity. Although in general CDIs with children of this age do not include comprehension questions, it has been found that the comprehension total for this CDI correlates more closely with receptive language as tested using a standardised instrument than the production total, and vice versa (Alcock & Krawczyk, 2006). Parents of all children completed this questionnaire.

Motor questionnaire. This questionnaire was adapted from two sources: the Ages and Stages screening instrument (Bricker & Squires, 1989), from which 10 items assessing gross and 9 items assessing fine motor development were taken, utilizing items from a range of the instrument's age-specific questionnaires, and the CDI – Words and Gestures (Fenson et al., 1994), from which 31 gesture items were taken, chosen as those where scores had not reached ceiling by 16 months (the oldest age for which normally the CDI – Words and Gestures would be used). Parents of children in the Combined Tests and the Other groups completed this questionnaire – in order to minimise the number of questionnaires each parent completed, most parents of children in the Motor group did not complete this questionnaire. However, for validation purposes, since the Ages and Stages questionnaire has only previously been validated for screening purposes, 13 parents from the Motor group also completed the gross and fine motor questions from our Motor questionnaire. Correlation between parent report and BSID Motor score was moderately high and significant for even this small group ($r^2_{13} = .69$, $p = .009$). The CDI – Words and

Gestures has previously been validated against laboratory testing of gestures (Fenson et al., 1994). See also Alcock & Krawczyk (2005) for further discussion of the measurement properties of the motor questionnaire.

Neither the Ages and Stages nor the CDI – Words and Gesture were originally designed to measure individual differences in typically developing children in this age range – the Ages and Stages is a screening questionnaire and the CDI – Words and Gestures is designed primarily for younger children, so adaptation of both was necessary. Internal reliability (Cronbach's alpha) was calculated for the gross motor questionnaire (.74), the fine motor questionnaire (.71) and the gesture questionnaire (.83).

Cognitive questionnaire. This questionnaire is a 25 item parent checklist of children's non-verbal cognitive skills, the PARCA, which has been validated against the BSID (Mental) (Saudino et al., 1998). Parents of all children completed this questionnaire, with the exception of some children in the Other group.

Socio-economic status and screening interview. This questionnaire was administered to all parents either over the telephone or in person, and asked about the family home, including post code, from which it is possible to obtain UK Indices Deprivation, higher values of which indicate more deprivation (Office of National Statistics, 2004), number of siblings, occupants of the home, and bedrooms, occupation (for the mother, her occupation prior to the birth of this child), education and residency with the child of both parents.

Years of education were coded from 1 to 4 (1 = left school at 16 or 17, 2 = left school at 18 and/or some vocational training, 3 = three years of university [Bachelor's degree], 4 = more than three years of university), and occupations were re-coded according to the collapsed (four-category) version of the National Statistics Socio-Economic Classification (Office of National Statistics, 2002). In addition questions were asked about any diagnoses of developmental or language delay in the index child, siblings, or first degree relatives, any hearing loss in the index child, and languages spoken in the home.

Results

Descriptives

Descriptives for the motor tests and questionnaires administered can be seen in Table 1. It can be seen that the measures chosen are capturing a good range of abilities, although some of the gesture measures may be approaching ceiling. Groups assessed on each measure are shown in the N column as follows: Motor group (M), Combined group (C), Other group (O), All children (A).

Table 1

Descriptives for tests and questionnaires assessing motor abilities

Assessment	N (group)	Mean score	Standard deviation	Minimum score	Maximum score	Maximum possible score
Gesture naming test	24 (M)	14.71	3.41	9	20	20
Meaningless gesture test	20 (M)	7.30	4.75	0	17	20
Gesture memory test	30 (M)	5.83	1.91	2	10	15
Single oral movement imitation	60 (M, C)	9.50	3.96	1	17	20
Single complex oral movement imitation	60 (M, C)	5.43	2.50	0	10	12
BSID (Motor)	30 (M)	6.47	2.65	1	11	13

gross motor items raw total						
BSID (Motor) fine motor items raw total	30 (M)	1.80	.76	1	3	4
Gesture questionnaire total	103 (C, O)	21.05	6.57	4	31	33
Gesture questionnaire symbolic gesture subtotal	103 (C, O)	7.45	3.63	0	13	13
Gross motor questionnaire total	101 (C, O)	15.08	2.58	4	18	18
Fine motor questionnaire total	101 (C, O)	10.45	2.89	4	18	18

First-order correlations

CDI – Production and CDI – Complexity were found to be skewed negatively, as was the Index of Multiple Deprivation and the Meaningless Gesture task, while the Gesture Naming task and the Gross Motor questionnaire were found to be skewed positively, so square root transformations of these variables are used in all analyses. First-order correlations between motor abilities (as measured by laboratory tests and parental questionnaires, dependent on group), and CDI scores will initially be considered, followed by first-order correlations of control variables (cognitive abilities and SES factors) with CDI and motor scores. A p-value of .05 was used throughout, and to control for multiple comparisons a False Discovery Rate (Benjamini & Hochberg, 2000) of 0.15 was applied to each group of correlations (correlations with language measures, correlations among motor measures, and correlations with SES/cognitive measures); only those correlations that remained significant are shown (at their raw p-values).

Because all children were assessed in some form on gross motor, fine motor and gestural abilities (either a laboratory test or a parent report questionnaire), standard scores could be calculated in addition for each of these abilities using the different assessment scores. These standard scores were calculated using the current population of children, calculating a standard score for either BSID (Motor) gross motor items or gross motor questionnaire total (Gross motor standard score); BSID (Motor) fine motor items or fine motor questionnaire total (Fine motor standard score); manual gesture tests total or gesture questionnaire total (Gesture standard score); and gesture naming or gesture questionnaire symbolic items subtotal (Symbolic gesture standard score).

Relationships between motor abilities and language abilities

These can be seen in Table 2. It can be seen that single oral movement imitation correlates with all measures of language, and that some gesture measures and gross and fine motor questionnaires correlate significantly with language measures, but that gross motor abilities as measured on the BSID (Motor) do not correlate with language abilities. Within gesture and gross/fine motor correlations with language, gesture measures correlate more strongly with CDI – Comprehension and gross/fine motor questionnaire scores correlate with CDI – Production and Comprehension but not Complexity.

Table 2

Correlations between motor measures and language measures. Figures in tables 2 through 5 show Pearson's r (N).

	CDI – Production	CDI – Comprehension	CDI - Complexity
Oral motor testing			
Single oral movement imitation	.30 (58)*	.40 (58)**	.36 (57)**
Single complex oral movement imitation subscale	.40 (58)**	.40 (58)**	.32 (57)*
Rate of production of speeded oral movements	n.s.	n.s.	n.s.
Gesture tests and questionnaires			
Total score on gesture task	n.s.	.50 (24)*	n.s.
Gesture naming task	n.s.	n.s.	n.s.
Meaningless gesture imitation	n.s.	n.s.	n.s.
Gesture memory	n.s.	.43 (29)*	n.s.
Gesture questionnaire total	.24 (101)*	.29 (101)**	.29 (98)**
Gesture questionnaire symbolic subscale	.30 (101)**	.25 (101)*	.32 (98)**
Gross and fine motor tests and questionnaires			
BSID (Motor)	n.s.	n.s.	n.s.
Gross motor questionnaire	.25 (99)*	.28 (99)**	n.s.
Fine motor questionnaire	.21 (100)*	.24 (100)*	n.s.
Standardised scores for motor abilities			
Standard score for gesture ability overall	.21 (117)*	.21 (117)*	.26 (112)**
Standard score for symbolic gesture ability	.30 (115)**	.34 (115) ***	.25 (116)**

Standard score for fine motor ability	.27 (119)**	.20 (119)*	n.s.
Standard score for gross motor ability	n.s.	n.s.	n.s.

* p < .05; ** p < .01; *** p < .001; n.s. not significant, in all tables.

Relationships among motor abilities

In Table 3 it can be seen that oral motor tests correlate significantly with some gesture tests. Although the rate of production of speeded oral movements does not correlate significantly with any of the language or any other motor measures, it correlates significantly with single oral movement imitation. Gesture subscales also do not correlate significantly with each other, although gesture and BSID (Motor) correlate significantly with single oral movement imitation. In addition, among the motor questionnaires, the gross and fine motor questionnaires correlate significantly with each other – r = .24 (101), p < .05 – but the gesture questionnaire does not correlate significantly with either of the other motor questionnaires.

Table 3

Relationships among motor tests (Pearson's R (n) is shown). There were no significant correlations among the gesture subtests; correlations between totals and subtotals for the same test are not shown.

Motor test	1.	2.	3.
1. Single oral movement imitation			
2. Single complex oral movement imitation subscale			
3. Rate of production of speeded oral movements	.53 (16)*	n.s.	
4. Total score for gesture tests	.68 (25)***	.64 (25)**	
5. Gesture naming	n.s.	.58 (22)**	n.s.
6. Meaningless gesture imitation	.64 (25)**	.62 (19)**	n.s.
7. Gesture memory	n.s.	n.s.	n.s.
8. BSID (Motor)	.39 (28)*	n.s.	n.s.

Relationships among language, cognitive and SES variables and between these and motor abilities

These can be seen in Table 4. In general, relationships were found between cognitive questionnaire scores and language measures, but not motor measures; although SES measures did not correlate with language abilities, father's employment showed a significant negative correlation (in the expected direction) with one gesture measure, while mother's and father's education showed significant negative correlations with scores on the gross motor questionnaire (children of less well educated parents had higher scores on this questionnaire). In addition, the Gesture questionnaire correlated significantly with the symbolic subscale of the PARCA, while the gross and fine motor questionnaires correlated significantly with the non-symbolic subscales of the PARCA, but not vice versa.

Table 4

Correlations between cognitive and SES measures, and language measures and motor measures (Pearson's R (n) is shown). Where a non-significant correlation was found for an overall scale, subscales are omitted from the table entirely unless significant correlations were found.

Language or motor measure	Cognitive q'aire symbolic subscale	Cognitive q'aire non-symbolic subscale	Mother's ed. level	Father's ed. level	Mother's employment	Father's employment
CDI – Production	.30 (83)**	n.s.	n.s.	n.s.	n.s.	n.s.
CDI – Comprehension	.41 (83)***	.46 (83)***	n.s.	n.s.	n.s.	-.24 (95)*
CDI -	.39	n.s.	n.s.	n.s.	n.s.	n.s.

Complexity	(82)***					
Single oral movement imitation	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Gesture test total	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Gesture memory	n.s.	n.s.	n.s.	n.s.	n.s.	-.70 (18)**
BSID (Motor)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Gesture q'aire non-symbolic items	.54 (68)***	n.s.	n.s.	n.s.	n.s.	n.s.
Gesture q'aire symbolic subscale	.50 (68)***	n.s.	n.s.	n.s.	n.s.	n.s.
Gross motor q'aire	n.s.	.43 (67)***	n.s.	n.s.	-.28 (90)**	-.28 (87)**
Fine motor q'aire	n.s.	.45 (68)***	n.s.	n.s.	n.s.	n.s.

Regression analyses

Novel analyses – analyses including oral motor test

Relationships of motor abilities to all three CDI scores were examined, with cognitive (cognitive questionnaire scores) and SES (father's occupation) measures added in a second step where appropriate. The two groups that had been tested on the oral motor tests – Motor and Combined Tests – were initially analysed separately as these groups had been tested using different combinations of tests. Following this, a joint analysis was carried out with all of these children who had done the oral motor testing, using the standard scores for gross motor, fine motor and manual gesture assessments. In the case where both scores on an overall motor scale and those on a subscale correlated significantly with a language measure, the motor measure with the larger correlation was included in the regression analysis. Where a motor or cognitive measure was divided into non-overlapping subscales and all or some subscales correlated significantly with a language measure, all the subtests that correlated significantly were included.

Motor group

Results are shown in Table 5. In summary, the regression models for CDI – Production and Complexity were significant, and single oral movement imitation had a significant association with these measures, while all other measures did not. The regression model for CDI – Comprehension in contrast was not significant, with no significant correlates emerging.

Combined Tests group

Results are shown in Table 6. In summary, all three models were significant (though only at the second step for CDI – Comprehension). For Production and Complexity, single oral movement imitation was significantly associated with language abilities even controlling for gesture and other abilities, and no other predictors were significant. For Comprehension the only predictor emerging overall as significant was the non-symbolic subscale of the cognitive questionnaire.

Table 5

Results of regression analyses examining influence of motor abilities on language measures, controlling for cognitive abilities and SES: Motor group

	Variable	B	SE B	β
CDI – Production				
Step 1 (R^2 = .17**)	Complex oral movements score	.71	.22	.41**
Step 2 (ΔR^2 = .004**)	Complex oral movements score	.70	.22	.41**

	Cognitive questionnaire symbolic items	.15	.31	.06 n.s.
CDI - Comprehension				
Step 1 (R^2 = .19 n.s.)	Complex oral movements score	14.22	9.85	.52 n.s.
	Gesture tests total score	-3.84	6.19	-.22 n.s.
Step 2 (ΔR^2 = .36 n.s.)	Complex oral movements score	8.20	10.03	.30 n.s.
	Complex oral movements score	-2.23	5.88	-.13 n.s.
	Cognitive questionnaire symbolic items	9.13	10.05	.29 n.s.
	Cognitive questionnaire non-symbolic items	3.28	6.83	.15 n.s.
	Father's employment score	-30.78	17.30	-.51 n.s.
CDI - Complexity				
Step 1 (R^2 = .16**)	Oral motor total score	.13	.04	.40**
Step 2 (ΔR^2 = .06**)	Oral motor total score	.10	.04	.33*
	Cognitive questionnaire symbolic items	.14	.09	.20 n.s.
	Cognitive questionnaire non-symbolic items	.08	.07	.15 n.s.

Table 6

Results of regression analyses examining influence of motor abilities on language measures, controlling for cognitive abilities and SES: Combined Tests group

	Variable	B	SE B	β
CDI – Production				
Step 1 (R^2 = .32*)	Complex oral movements score	.84	.33	.45*

	Gross motor questionnaire score	3.54	2.42	.24
	Fine motor questionnaire score	.01	.26	.01
	Gesture questionnaire symbolic subscale	-.19	.20	-.16
Step 2 (ΔR^2 = .05*)	Complex oral movements score	.84	.33	.45*
	Gross motor questionnaire score	3.81	2.38	.26
	Fine motor questionnaire score	-.04	.26	-.02
	Gesture questionnaire symbolic subscale	-.32	.22	-.27
	Cognitive questionnaire symbolic subscale	.63	.42	.24
CDI - Comprehension				
Step 1 (R^2 = .19 n.s.)	Complex oral movements score	5.04	6.37	.16
	Gross motor questionnaire score	35.44	45.91	.15
	Fine motor questionnaire score	4.19	5.22	.14
	Gesture questionnaire score	2.25	2.28	.19
Step 2 (ΔR^2 = .25*)	Complex oral movements score	3.31	5.65	.11
	Gross motor questionnaire score	6.95	47.55	.03
	Fine motor questionnaire score	-2.25	5.03	-.08
	Gesture questionnaire score	.24	2.29	.02
	Cognitive questionnaire symbolic subscale	9.00	7.73	.20
	Cognitive questionnaire non-	16.51	6.26	.52*

	symbolic subscale			
	Father's employment score	-16.90	13.88	-.20
CDI - Complexity				
Step 1 (R^2 = .18*)	Oral motor total score	.15	.06	.45*
	Gesture questionnaire score	-.05	.06	-.13
Step 2 (ΔR^2 = .13*)	Oral motor total score	.12	.06	.35*
	Gesture questionnaire symbolic subscale	-.08	.06	-.22
	Cognitive questionnaire symbolic subscale	.26	.13	.32
	Cognitive questionnaire non-symbolic subscale	.14	.09	.22

All values in the β column are non-significant unless noted otherwise.

Joint analysis of Motor and Combined Tests groups

To increase power, data from these two groups, who both did the oral motor testing, were analysed together, using standardised scores as outlined above. These results can be seen in Table 7. Single oral movement imitation had a significant relationship with both CDI – Production and CDI – Complexity even when other motor abilities and cognitive abilities were controlled for; in fact only symbolic cognitive abilities had any additional significant relationship, and only with Complexity. In contrast, no motor ability had a significant relationship with CDI – Comprehension, where the non-symbolic subscale of the cognitive questionnaire and Father's employment were significant associates of language comprehension. Figure 1 shows the correlation between CDI – Production and single complex oral movement imitation.

Table 7

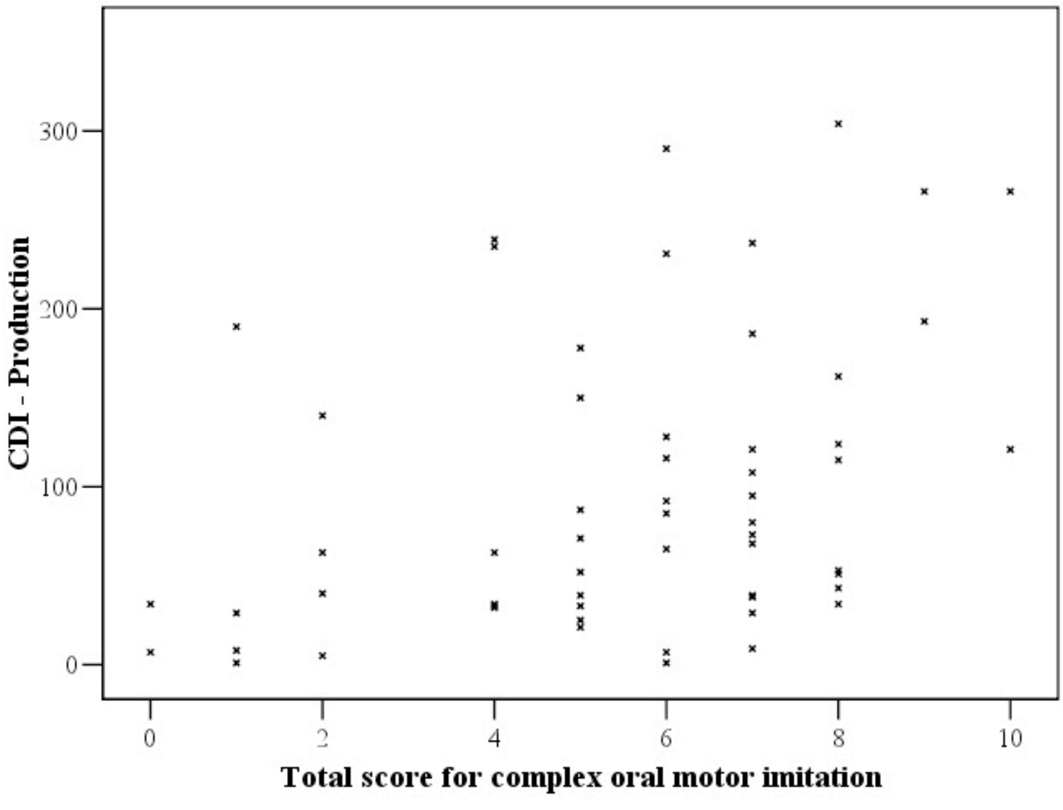
Results of regression analyses examining influence of motor abilities on language measures, controlling for cognitive abilities and SES: Motor tests group and

Combined Tests group, joint analysis.

	Variable	B	SE B	β
CDI – Production				
Step 1 (R^2 = .22**)	Complex oral movements score	.79	.27	.45**
	Fine motor standard score	.84	.60	.18
	Gesture standard score	-.11	.74	-.02
Step 2 (ΔR^2 = .02*)	Complex oral movements score	.84	.28	.48**
	Fine motor standard score	.79	.60	.17
	Gesture standard score	-.42	.79	-.09
	Cognitive questionnaire symbolic items	.37	.35	.15
CDI - Comprehension				
Step 1 (R^2 = .18 n.s.)	Complex oral movements score	9.08	5.75	.29
	Fine motor standard score	17.16	11.50	.23
	Gesture standard score	7.95	15.65	.09
Step 2 (ΔR^2 = .25**)	Complex oral movements score	5.15	5.16	.16
	Fine motor standard score	-.11	11.15	.00
	Gesture standard score	1.52	14.35	.02
	Cognitive questionnaire symbolic subscale	8.90	6.04	.21
	Cognitive questionnaire non-symbolic subscale	13.90	4.69	.45**
	Father's employment score	-24.05	11.35	-.29*
CDI - Complexity				
Step 1 (R^2 = .16*)	Oral motor total score	.15	.05	.47**
	Gesture standard score	-.19	.23	-.13

Step 2 (ΔR^2 = .10**)	Oral motor total score	.14	.05	.44**
	Gesture standard score	-.35	.23	-.25
	Cognitive questionnaire symbolic items	.20	.10	.27*
	Cognitive questionnaire non-symbolic items	.10	.07	.18

Figure 1 Scatter plot of scores on complex oral motor subscale of oral movement imitation test and CDI - Production



Replication analysis – excluding oral motor test

A final regression analysed the association between language abilities and motor performance in the Other group; this group was not tested on oral motor tests so this analysis serves to examine residual relationships between limb (upper and lower) motor control and language abilities. This analysis is therefore a replication of previous studies which have only looked at gross and fine motor abilities and manual gestural abilities. These data can be seen in Table 8.

It was found that there was a significant relationship between scores on the gross motor questionnaire and CDI – Production, but only after cognitive abilities were controlled for; there was also a significant relationship between scores on the symbolic subscale of the cognitive questionnaire and CDI – Production. For CDI – Comprehension there was a significant relationship with the total score on the gesture questionnaire, but once scores on the cognitive questionnaire were controlled for this relationship did not remain. Rather, CDI – Comprehension was strongly associated with the non-symbolic subscale of the cognitive questionnaire and with father's employment, and also associated with the symbolic subscale of the cognitive questionnaire. Finally, CDI – Complexity was significantly associated with only the two subscales (symbolic and non-symbolic) of the cognitive questionnaire.

Table 8

Results of regression analyses examining influence of motor abilities on language measures, controlling for cognitive abilities and SES: Other group

	Variable	B	SE B	β
CDI – Production				
Step 1 (R^2 = .09 n.s.)	Gross motor questionnaire	2.82	1.51	.25
	Fine motor questionnaire	.05	.21	.03
	Gesture questionnaire symbolic subscale	.20	.15	.16
Step 2 (ΔR^2 = .10*)	Gross motor questionnaire	3.30	1.44	.29*
	Fine motor questionnaire	-.01	.20	-.01
	Gesture questionnaire symbolic	-.05	.16	-.04

	subscale			
	Cognitive questionnaire symbolic subscale	.91	.33	.38**
CDI - Comprehension				
Step 1 (R^2 = .16*)	Gross motor questionnaire	9.77	27.21	.05
	Fine motor questionnaire	4.48	3.90	.16
	Gesture questionnaire total score	4.19	1.54	.35**
Step 2 (ΔR^2 = .27***)	Gross motor questionnaire	7.49	25.63	.04
	Fine motor questionnaire	-1.30	3.62	-.05
	Gesture questionnaire total score	1.80	1.61	.15
	Cognitive questionnaire symbolic items	13.12	5.29	.33*
	Cognitive questionnaire non-symbolic items	12.61	3.84	.43**
	Father's employment score	-20.14	9.81	-.23*
CDI - Complexity				
Step 1 (R^2 = .05 n.s.)	Gesture questionnaire total score	.05	.03	.23
Step 2 (ΔR^2 = .17**)	Gesture questionnaire total score	.00	.03	.01
	Cognitive questionnaire symbolic subscale	.27	.10	.38**
	Cognitive questionnaire non-symbolic subscale	.14	.06	.27*

* $p < .05$; ** $p < .01$; *** $p < .001$; n.s. not significant. All values in the β column are

non-significant unless noted otherwise.

Discussion

In this study we examined the concurrent relationships of motor abilities and language abilities in children aged 21 months, a time of maximal individual differences in language abilities. Previous studies have indicated that manual gesture abilities are especially closely related to language abilities in development, and have suggested a variety of theoretical reasons why this might be the case.

Few studies have however examined the relationship of oral motor abilities to language development, and those that have did not include other motor abilities that are known to have relationships to language, nor cognitive and SES measures as controls. In general these studies have either examined very simple oral movements and their relationship to babbling and early speech (MacNeilage & Davis, 1993; MacNeilage et al., 1997; Moore & Ruark, 1996), or have found associations between oral motor control and delayed or disordered speech and language (Laine, Pahkala, Jaroma, & Qvarnstrom, 1992; Pahkala & Qvarnstrom, 2002).

Here we have found that regardless of which other motor correlates of spoken language or which cognitive correlates are included in analyses, imitation of single oral movements emerges as the only significant correlate of spoken language production at this age after other abilities have been controlled for. An analysis analogous to previous studies, looking at the relationship of non-oral motor abilities to language, controlling for cognitive abilities, suggested that gross motor abilities alone remained significantly associated with spoken language production after other abilities had been controlled for. Interestingly, although some previous studies have suggested that in typical development gross motor abilities are not associated with language development (Bates, 1979; Bonvillian et al., 1983), impairments in gross motor control are frequently found in children with developmental language impairments (Hill, 2001).

Turning to spoken language comprehension, motor abilities here in contrast do not emerge as strong correlates of the CDI – Comprehension measure. For this and other reasons, it is unlikely that relationships between motor control and language are purely due to some children both comprehending the instructions for the motor tests, and having better spoken language. Apart from the general instruction that children should imitate (both gesture tests, gross and fine motor tests, and single oral movement imitation) and/or manipulate the objects they were given (gesture naming test, gross and fine motor tests, and oral motor imitation), it would have been possible for a child to perform well on all tests without comprehending details of the instructions.

Indeed, in most tasks instructions were deliberately vague in order to make sure that the test did not rely on comprehension (children were not asked to "brush your teeth" but given objects such as a toothbrush and given the same instruction for each object, "show me what you do with this"; meaningless gestures were not described, and neither were the specific movements needed for single oral movement imitation (children were asked to "lick off the honey" rather than told to "lick from side to side" which is the only efficient way to remove honey from the lips).

Single oral movement imitation is not associated with spoken language comprehension after other correlates have been accounted for, while scores on the gesture questionnaire are significantly associated with comprehension only before cognitive and SES measures were entered into the analysis, and only in the analysis involving the Other group, where no oral motor tests were carried out. It might be that this lack of association with motor abilities is due to colinearity between different aspects of motor abilities. However, although motor abilities seemed to have some association with spoken language comprehension in the Other group analysis (analogous to previous studies that have included limb motor control only), once cognitive and SES measures were controlled for in this analysis, only scores on the cognitive questionnaire (both symbolic and non-symbolic) and father's employment were significantly correlated with CDI – Comprehension. In the analyses of the

Motor and Combined Tests groups, the non-symbolic subscale of the cognitive questionnaire and father's employment both showed independent significant associations with CDI – Comprehension. Scores on the non-symbolic subscale of the cognitive questionnaire overall therefore showed the strongest relationship overall with language comprehension.

Finally looking at grammatical complexity of spoken language at this age, when the association of CDI – Complexity with single oral movement imitation was examined, regardless of which covariates were entered into the regression equation, oral motor ability also emerged as a significant predictor, either solely, or in conjunction with the symbolic subscale of the cognitive questionnaire (in the Joint groups analysis). When oral motor abilities were excluded from the regression equation, in the Other group analysis, scores on the symbolic subscale of the cognitive questionnaire emerged as a highly significant correlate of grammatical complexity, while scores on the non-symbolic subscale were also significant.

Returning to our predictions and to previously suggested theories of the association of motor control with language abilities, the most consistently confirmed hypothesis was that spoken language will be associated with motor control in development because of the use of the *same articulators and/or adjacent neural representation*. These possibilities are very closely linked, and it is arguable that they are inseparable, though logically it may be possible to distinguish between them, but we cannot do so from these data. However, with language production (and grammatical development, here measured with parent observation of complex language production rather than comprehension) oral motor abilities are the only significant motor correlate when other abilities are controlled for.

We made other theoretical suggestions in addition. One of these is that we would find an association due to the *symbolic nature* of both manual gesture and language abilities. Our data failed to confirm this hypothesis. Our symbolic gesture task – the gesture naming task – did not significantly correlate with language abilities at this age, though this task was relatively easy for the children in the study and ceiling level performance cannot be discounted. Children in the Combined Tests and Other groups were assessed on symbolic gesture using a subscale of the manual gesture questionnaire, and scores on this subscale did correlate with spoken language production and grammatical complexity. However, after controlling for other motor abilities and/or cognitive abilities this relationship was no longer significant. It has been found in the past that spoken language and symbolic gesture may be “out of step”, with one ability improving as the other reaches a plateau (Bates & Dick, 2002). It is possible that this group of children is at such a stage; certainly, there was some indication of a ceiling effect on the gesture naming task, indicating children had reached a common stage of development in some aspects of symbolic gesture.

When both symbolic gesture and scores on the symbolic subscale of the cognitive questionnaire were entered into the same regression analysis, it was the symbolic cognitive score that emerged as significant. It seems that there is some truth to the symbolic basis for manual gesture-language association, but that symbolic abilities that are not just motor in nature are more closely related to spoken language abilities.

The next possibility – a common association of *working memory abilities* with motor control and language development (Klapp, 2003) – has also not been confirmed. Although there was a significant association between the gesture memory task and some aspects of language development, this did not remain significant after covariates were controlled for. Most studies associating working memory abilities with language development and abilities have used nonword repetition, or another working memory task requiring speech articulation and auditory processing or discrimination (Gathercole, 2006). Our task required manual motor control and reproduction of a motor sequence from memory, but no articulation or auditory processing, suggesting that it may be the phonological aspects of the phonological working memory tasks (either production or auditory processing or both) that drive their relationship to language abilities.

We also suggested that theories of *embodied cognition* could explain motor/language links. This possibility relies on motor experience enhancing language representation for related items and/or vice versa. It is likely that these links would be stronger between gesture and language than between oral motor control and language: most non-speech actions performed by humans are performed with the limbs, not the mouth. This link also relies on the individual having experience with the gesture concerned, or on the action being nameable. The lack of a link between language production or perception and performance of familiar gestures in the gesture naming task makes this explanation less likely. However, although all the items in the oral motor control task were performed both to imitation and with props to assist children, the tester named props and gave a broad label to individual items, and encouraged children verbally. Even without description, children who can verbally label movements may be at an advantage in such tasks. We might expect, though, that this advantage would also extend to manual gesture tasks and to gross and fine motor tasks, but no independent link was found between these other motor tasks and spoken language abilities. This link is interesting, though, and deserves further investigation.

The final possibility – *mirror neuron* relationships between manual and/or oral motor abilities, and language abilities, rests partly on representation of both auditory processing and motor control by the same neurons: motor control and language perception are suggested to be related due to a common neural representation, as has been found for gesture production and auditory perception in primates (Arbib, 2005; Kohler et al., 2002). We did not find support for this hypothesis: although a strong relationship between motor control (primarily oral motor control) and language production was found, no such relationship with language comprehension was seen, which would be expected under this framework. This was despite the fact that language comprehension and production were measured with subscales of the same questionnaire, the CDI – Comprehension and Production respectively.

Instead, language comprehension was most closely associated firstly with scores on the non-symbolic subscale of the cognitive questionnaire, and then with one SES measure (father's employment), and with scores on the symbolic subscale of the cognitive questionnaire. In addition, the very different pattern of associations for CDI – Comprehension and CDI – Production suggests that our decision to assess both of these aspects of language development using parent report was justified.

We hypothesised in addition that spoken language abilities would not be associated with gross and fine motor abilities in this, typically developing, group. This was confirmed: although when oral motor abilities are not controlled for, there is some link remaining between gross motor control and spoken language abilities, once this is controlled for, no significant relationship between either gross or fine motor abilities and language development remained in any analysis.

Measures used in the study

In this study we examined children's motor control using an experimental testing paradigm for a subgroup, but in order to expand the sample size but not fatigue children, we used validated parent-report questionnaires for a larger group of children, who had been tested in the laboratory on other measures. We might be cautious therefore if our main finding were a strong correlation between parent report measures, which could be due to a halo effect or variable parental accuracy in completing questionnaires.

Although we did find some significant correlations between different parent report measures that remained when other factors were controlled for, such as a strong correlation between CDI – Comprehension and the non-symbolic subscale of the cognitive questionnaire, other correlations that might be expected were not found. For example, although both the symbolic and the non-symbolic subscales of the cognitive questionnaire correlated with language measures, and both emerged as significant correlates of language comprehension in regression analyses, these two subscales – composed of items interleaved with each other on one questionnaire – did not correlate significantly with each other.

Our main finding of significance was the very strong relationship between oral motor abilities and language production (both vocabulary and grammatical complexity). Although some of the motor abilities with some groups of children were assessed using parent report, oral motor abilities were assessed in the laboratory only. We might be more conservative in interpreting this finding if it involved correlation between measures of language and motor abilities taken in the same laboratory session, so that children's performance on the day or lack of familiarity with the tester might affect performance on both items. The very different nature of the oral motor tests and the CDI makes us confident about the genuine nature of this association.

Summary and conclusions

In summary, we found strong relationships between oral motor abilities and language production abilities at the age of 21 months, which cannot be accounted for by other motor control abilities, nonverbal cognitive abilities, or SES measures. We suggest that a common articulatory basis for spoken language and oral motor control underpins this relationship, probably due to a shared neural substrate underlying both uses of the mouth. This relationship may well be related to a common need for coordination of the oral motor apparatus, rather than any need for rapid movement that may be required in speech, as the speed at which children could repeat oral movements was not related to language, and imitation of complex oral movements was more closely related to vocabulary production than was imitation of single oral movements overall.

We did not find that manual gesture had any independent relationship with language – either in production or comprehension – once concurrent oral motor abilities and cognitive abilities had been controlled for. We also found no independent relationship between any motor ability, either involving oral or limb movements, and language comprehension. Rather, the strongest relationship with language comprehension was non-symbolic cognitive abilities. This is in line with previous research suggesting that language comprehension and its difficulties are closely related to nonverbal cognitive difficulties (Bishop, North, & Donlan, 1995; Price et al., 2000).

Our findings regarding oral motor control and typical language development extend previous research which has found a link between oral motor control and very early typical speech development (MacNeilage & Davis, 1993; MacNeilage et al., 1997) as well as associations in delayed or disordered speech and language development (Alcock et al., 2000; Dewey et al., 1988; Laine et al., 1992; Pahkala & Qvarnstrom, 2002). It seems that it is not just the case that some children with dyspraxic difficulties in their speech may also have dyspraxic difficulties in their oral motor control. Oral motor control is strongly related to language production ability also in a typically developing group of young children.

This study is cross-sectional and correlational, so that the direction of causality can obviously not be determined. Follow-up of children's language and motor abilities at later ages is clearly necessary; as in this study, the types of cognitive and SES factors that are known to be related to language abilities must be controlled for. In addition, further investigation of oral motor abilities in children with other types of speech and language difficulties, including those without any clear dyspraxic difficulties, is warranted. Children with Down Syndrome (Kumin & Adams, 2000) and autism (Adams, 1998; Amato & Slavin, 1998; Gernsbacher et al., 2008) are known to have difficulty with oral motor control. Children with specific language impairment but without clinical dyspraxia have been shown to have difficulty with gross and fine motor control (Hill, 2001), so investigation of fine oral motor control in this group would be particularly interesting.

Many children are late to talk, but not all of them go on to have speech and language impairment (Rescorla, Roberts, & Dahlsgaard, 1997). If motor abilities at younger ages predict language ability at older ages, then assessment of motor abilities holds promise for early identification of children with speech and language impairment.

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