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Article

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Abstract

Purpose: This study examined the relationship between sensorimotor abilities, gesture, and language in prelinguistic typically developing children from an embodied cognition perspective.
Method: Participants included a total of 54 typically developing infants and toddlers between the ages of 9 months and 15 months. All participants were administered the Mullen's Scale of Early Learning (MSEL) and two gesture samples were obtained and coded. The MSEL was used to analyze sensorimotor and language abilities which were explored in relation to gesture.
Results: Results established that sensorimotor skills are related to gesture and expressive language, but not receptive language. Visual reception was most highly related to gesture whereas gross motor skills were most highly related to expressive language.
Conclusion: This study supports an embodied development perspective with sensorimotor skills relating to gesture and language development. We emphasize the need for interdisciplinary collaboration in treatment and assessment of children, considering the entire developmental profile.

Keywords: Embodied cognition, sensorimotor, language, gesture, development.

Introduction

Examining a child's early development can provide a clear view about how the body and mind grow and mature. As a child masters each developmental milestone we can make predictions about the child's future abilities. Certain observable skills in early childhood are known to be associated with linguistic, cognitive, and motor outcomes. Gesture use, for example, is associated with later verbal language development (Rowe & Golden-Meadow, 2009), babbling is predictive of first word onset (McGillion, 2017), and fine and gross motor skills are predictive of later language outcomes (Gonzalez et al., 2019). There is a connection between individual skills and their impact on later development; however, a need for continued exploration of the relationships between these developmental skills persists.

Although research investigating individual developmental skills in infants and toddlers is abundant, the mechanism through which their sensorimotor experience supports early development of these skills deserves further exploration. One explanation for this relationship is embodied cognition, a theory suggesting that an individual's sensorimotor experiences uniquely contribute to their overall skill development, including language (Lackoff & Johnson, 1980, 1999). Embodied cognition posits that the human mind and body are interconnected, and that many aspects of cognition, including language, are related to the body's sensorimotor interactions with the world at large.

The initial evidence motivating embodied cognition science includes four critical components. The first is that gesture is naturally used in conjunction with language. The use of gesture not only assists in communication but facilitates language processing (McNeill, 1992). Second, vision guides action and the feedback provided by movement impacts visual processing to some extent (O'Regan & Noe, 2001). Third, the mirror neuron system is activated in response to an observed action (Rizzolatti & Craighero, 2004). The fourth and final exemplar for embodied cognition science draws from the fact that cognitive tasks such as recall and memory are assisted by using our body, movement, and the immediate surroundings to cue ourselves (Donald, 1991).

Embodied cognition concepts have primarily been tested via behavioral and physiological research on adults (Hauk et al., 2004) and older elementary school aged children (Adams et al., 2018; Berenhaus et al., 2014; Porter, 2012). Studies exploring these concepts in younger children are limited and could provide valuable insight into human development and how different systems interact during this process. This information is of great importance because understanding how sensorimotor abilities interact with the development of various cognitive processes, including gesture and language, provides valuable information about typical development and has the potential to guide clinical decision making.

Gesture and Language Development

The relationship between gesture and language development is well established in the literature. (Bates & Dick, 2002; Bates et al., 1979; Werner & Kaplan, 1963). For example, gesture use at 18 months of age is predictive of vocabulary and sentence complexity at 42 months of age (Rowe & Goldin-Meadow, 2009), the content of first words spoken and symbolic gestures used is very similar in content (Bates & Dick, 2002), and early gesture use can predict early verbal vocabulary (Iverson & Goldin-Meadow, 2005), onset of two word combinations (Iverson & Goldin-Meadow, 2005), and later vocabulary competence (Rowe & Goldin-Meadow, 2009). In atypical populations, word production usually does not begin until symbolic gestures have appeared (Happe &

Frith, 1996; Singer-Harris et al., 1997). Children delayed in use of gesture may also be delayed in later stages of language development (Thal et al., 1997). While the relationship between gesture and language is clear, an area in need of further exploration is understanding how, or if, a child's sensorimotor abilities are related to the development of gesture and language.

Sensorimotor, Gesture, and Language Development

Studies have examined the relationship between sensorimotor skills and gesture and language development in young children. While limited in number, these studies support that sensorimotor skills play a role in both the development of gesture and language. A series of studies conducted by Choi and colleagues (2018, 2019) found that fine motor skills, including speech production and hand movements, are predictive of later expressive language ability; one-year-olds' pointing, an especially predictive fine motor skill, is correlated with later language skills at ages three and four (Luike et al., 2019); and 6-9-month-old infants' gross motor usage of their arms is correlated with their vocalizations (Iverson & Fagan, 2004). Additionally, early onset of walking is predictive of language abilities at two years of age (Luike et al., 2019); babies' visual attention, when coordinated with their own vocalizations and gestures, is predictive of later expressive vocabulary (Donnellan et al., 2020); and joint attention, which relies on visual attention, mediates the link between language and motor development for typically developing siblings of children with ASD, a connection that reflects tenets of embodied cognition (Bruyneel et al., 2019). Taken together, these studies suggest that sensorimotor skills are an important component of young children's gesture and language development; however more studies are needed to understand this relationship more deeply.

The goal of the current study is to increase understanding of the way specific sensorimotor skills correlate with gesture and language abilities. More specifically, an embodied cognition framework is used to interpret how visual reception, fine motor, and gross motor interact with gesture use and language development. Understanding this relationship is important because it provides researchers and clinicians with information about typical development. Furthermore, it has the potential to impact future clinical decision making and can support the need for multidisciplinary assessment and intervention of children. This study addresses the following research questions:

1. Is there a relationship between sensorimotor skills and gesture use in typically developing prelinguistic children?
2. Is there a relationship between sensorimotor skills and language abilities in typically developing prelinguistic children?

Methods

The research questions for this study are original. The methodology and data were part of a larger research study conducted by the first and fourth author of this study (Stewart et al., 2021). Appropriate approval from the University of Nevada, Reno (UNR) Institutional Review Board (IRB) was obtained.

Participants

A total of 54 typically developing children, 34 males and 20 females, between the ages of 9 and 15 months participated in this study. Participants were recruited from the following locations in northern Nevada: day cares, preschools, early learning centers, mothers' groups, doctors' offices, and churches. Inclusion criteria comprised of the following: a) children between 9-15 months of age, b) passed newborn hearing screenings, c) no history of intervention services or previous diagnoses, and d) developmental profiles within normal limits. Information relating to hearing screenings and previous interventions and diagnoses were collected via parent report. Developmental profile was assessed with the Mullen Scales of Early Learning (MSEL; Mullen, 1995). All subtests of the MSEL were administered by a licensed speech and language pathologist. See Table 1 for participant demographics.

Table 1
Participant demographics

	Total (N = 54)
CA Mullen's (M (SD)):	11.37 (1.78)
CA Video (M (SD)):	11.59 (1.74)
Gender (M, F):	20, 34
Race	
Black:	2
Hispanic:	5
White:	36
Mixed:	11
Mother Education	
Beyond Bachelors:	12
Bachelors:	19
Associates or some college:	15
High School Diploma:	7
No High School diploma:	1
Not reported:	0
Father Education	
Beyond Bachelors:	9
Bachelors:	9
Associates or some college:	12
High School Diploma:	17
No High School diploma:	4
Not reported:	3

Note. CA = Chronological age in months; M = Mean; SD = Standard Deviation.

Instruments

The Mullen Scales of Early Learning (MSEL)

The MSEL is an individually administered comprehensive measure of cognitive and motor functioning for infants and preschool children from birth through 68 months of age. This standardized assessment has been determined to have good reliability and validity and consists of five subtests: Visual Perception, Gross Motor, Fine Motor, Receptive Language, and Expressive Language. The gross motor subtest assesses a child's central motor control and mobility; the visual reception subtest assesses a child's visual input decoding, oculomotor and visualmotor operations, visual discrimination, and visual memory; the fine motor subtest assess a child's fine motor coordination; the receptive language subtest assesses a child's understanding of verbal directions, auditory-spatial and auditory-quantitative concepts, memory for commands, and general information; and the expressive language subtest assess a child's ability to express various concepts through the use of spoken language.

Each subtest of the MSEL yields a raw score, which can then be transformed into a T-score and a percentile rank. The raw score obtained on each subtest can also be used to calculate an age equivalent. The mean T-score on the Mullen's is 50, with scores falling between 40 and 60 considered to be within normal limits or typically developing. Scores that fall above 60 are considered above average, whereas scores falling below 40 are considered below average. In addition to each subtest, the Mullen's provides an *Early Learning Composite*. This score is representative of an average of the child's performance on all subtests. The *Early Learning Composite* is calculated by summing the T-Score's obtained on the above five subtests. For the Early Learning Composite, the mean standard score is 100, with scores falling within the 85-115 range considered to be within normal limits. Scores falling above 115 are considered to be 'above average', whereas those falling below 85 are considered to be 'below average'.

Procedure

In order to not interrupt the child's daily routine and accommodate the needs of the parents and/or caregivers, data collection took place in a quiet room at several different venues dependent on parent preference. These locations included: a) the child's home, b) the child's day care, preschool, or early learning center, or c) a university clinic. The following individual(s) were present during each session: parent/caregiver, teacher, investigator, and/or a research assistant(s).

Data collection took place across two separate sessions occurring within one week of one another, each approximately 45 minutes in duration. Session one consisted of obtaining consent, completion of the parent questionnaire, and administration of the MSEL. Session two consisted of the gesture sampling. See Table 2 for descriptive results from the MSEL.

Table 2

Descriptive statistics from the MSEL

	Total (N = 54; M, SD)
Gross Motor	
Raw Score	16.07 (3.19)
T-Score	54.07 (8.45)
Visual Reception	
Raw Score	17.28 (1.91)
T-Score	63.56 (8.05)
Fine Motor	
Raw Score	16.28 (1.89)
T-Score	62.19 (6.38)
Receptive Language	
Raw Score	14.94 (8.62)
T-Score	54.11 (6.93)
Expressive Language	
Raw Score	12.31 (2.35)
T-Score	51.87 (6.88)
Early Learning Composite	
Standard Score	116.43 (9.20)

**Note.* The mean T score is 50 with a standard deviation of 10. The mean standard score is 100 with a standard deviation of 15.

Session One

The first session involved obtaining consent, completion of a parent questionnaire, and administering the MSEL. Informed consent was obtained from the parent or legal guardian of all participants that participated in this study. The parent questionnaire was also completed by the parent or legal guardian of the participants and collected demographic information and basic developmental histories. A licensed speech and language pathologist, administered all five subtests of the MSEL to all potential participants. If a participant obtained scores within normal limits on all five subtests of the MSEL a time was scheduled for the second session, gesture sampling, to be conducted. If a participant obtained scores below normal limits on any of the subtests of the MSEL concerns were discussed with the parent or caregiver and the appropriate referral(s) was made. Subsequent to assessment, parents were provided with a report outlining the results of testing.

Session Two

The second session involved gesture sampling. The procedure for gesture sampling was adapted from Wetherby et al. (1988) and consisted of obtaining two video recordings: an unstructured observation and a structured observation. A combination of structured and unstructured procedures is the best way to accurately sample communication in young children (Wetherby & Rodriguez, 1992). Observing a child in an unstructured setting allows for the child to behave in a naturalistic manner; however, does not always allow for the child to display the full range of communication the child is capable of. Observation of a child in a structured setting allows the clinician or experimenter to create opportunities for the child to engage in communication. Both observations were approximately 15 minutes in duration.

The unstructured observation always occurred first in order to allow the child to acclimate to the interactant and/or setting. For this observation, the interactant was a research assistant or investigator. The child was allowed to play with a minimum of five of the following toys across a fifteen-minute time span: ball popper, book, pop tube, ball and hammer toy, bubbles, star stacker, and an interactive ball. The interactant was instructed to respond to the child's communicative attempts, but not to elicit them in any way. Examples of appropriate, natural responses, included expanding on what the child said or did, commenting about something the child said or did, laughing/clapping in response to a child's actions, and engaging in parallel or interactive play with the child (Wetherby et al., 1988).

The structured observation occurred second and ensured that all participants had the same opportunities to engage in the various gesture types. For this observation, the children were seated in their parent or caregivers lap at a table presented with activities adapted from the Early Social Communication Scales (ESCS; Mundy et al., 1996). The ESCS is a structured observation tool designed to provide measures of nonverbal communication skills of children 8-30 months of age. The activities from the ESCS were used to encourage children to use a broad array of gestures, not elicit them. The investigator or research assistant presenting the participant with the sequence of structured activities from the ESCS was once again instructed not to direct the behavior of the child but respond in a natural manner.

Video Coding

For the unstructured and structured video observations, all videos were edited to stop at 30 second increments and a time stamp was incorporated. This was done to improve reliability and accuracy of the coding. A coding system was created to identify frequency of gesture. All videos were coded by two undergraduate research assistants blind to the purpose of the research study. For each video, the 30-second video segments were watched and the coders tallied the total number of gestures occurring in each segment. When a gesture spanned across two time segments, the gesture was coded in the time segment which it began. In the event that a gesture involved multiple repetitions of the same motor movement (e.g. clapping), this was coded as a single gesture. For the purposes of this study, gestures were defined as intentional motor movements, which are interpretable by others, used for the purpose of communication (Watson et al., 2013). Eye contact, verbalizations, vocalizations, and smiling occurring in isolation were not included in this definition. Gestures occurring in isolation or in combination with eye contact, verbalizations, vocalizations, and smiling were included. To obtain total gesture count, the frequency data for each 30-second segment was tallied and divided by the duration of the video segment resulting in total frequency of gestures used per minute.

Reliability

Twenty percent of the total sample was double coded to determine interrater reliability. Based on Pearson's Product-Moment Correlation, the reliability between the two coders was very strong for the total frequency ($r = .97$) and frequency of behavior regulation ($r = .96$) measures. The reliability between the two coders for the frequency of social interaction gestures ($r = .75$) and the frequency of joint attention gestures ($r = .74$) measures were strong.

Data Analysis

To investigate the relationships between sensorimotor skills and gesture, and sensorimotor skills and language abilities, four multiple linear regression analyses were utilized. Predictor variables included the following sensorimotor abilities as measured by the MSEL: gross motor, fine motor, and visual reception. Criterion variables included gesture frequency in a structured setting, gesture frequency in an unstructured setting, expressive language, and receptive language. Prior to utilizing the multiple linear regression analyses, the intercorrelation matrix was examined and no issues with multicollinearity between predictors was observed. A post-hoc power analysis was conducted using G*power (Faul et al., 2009). The power of this study was determined to be 0.88. Results from the ongoing larger study have indicated that participants used significantly higher frequencies of gesture in the structured setting when compared to the unstructured setting. Therefore, these two conditions were analyzed separately when applicable.

Results

Sensorimotor and Gesture

In the structured setting, results of a multiple linear regression analysis indicate that sensorimotor motor abilities had a low to moderate effect size, that is, 17% of the variance in frequency of gesture use ($R = .42$, $R^2 = 0.17$; $F(3, 50) = 3.40$; $p < .05$) is accounted for by sensorimotor abilities. Each sensorimotor skill was then examined for individual contribution to the overall prediction of frequency of gesture use. Gross motor ($\beta = .11$, $t(52) = .55$, $p \geq .05$), visual reception ($\beta = .33$, $t(52) = 1.82$, $p \geq .05$), and fine motor ($\beta = -.01$, $t(52) = -.03$, $p \geq .05$) did not predict gesture abilities independently; however visual reception was nearing significance ($p = .08$). See Table 3.

In the unstructured setting, results of a multiple linear regression analysis indicate that sensorimotor motor abilities had a low to moderate effect size, that is, 15% of the variance in frequency of gesture use ($R = .39$, $R^2 = 0.15$; $F(3,50) = 3.04$; $p < .05$) is accounted for by sensorimotor abilities. Each sensorimotor skill was then examined for individual contribution to the overall prediction of frequency of gesture use. Visual reception was found to be significantly related to frequency of gesture use ($\beta = .37$, $t(52) = 1.99$, $p < .05$); however, gross motor ($\beta = .03$, $t(52) = .20$, $p > .05$) and fine motor ($\beta = .00$, $t(52) = -.02$, $p > .05$) were not. See Table 3.

Table 3

Relationships between Gesture and Sensorimotor Skills

Predictor Variables	β	t	R	R^2	F
Structured Setting			.42	.17	3.40*
Gross motor	.11	.55			
Visual reception	.33	1.82			
Fine motor	-.01	-.03			
Unstructured Setting			.39	.15	3.04*
Gross motor	.03	.20			
Visual reception	.37	1.99*			
Fine motor	-.00	-.02			

Note. N = 54, *$p < .05$; **$p < 0.01$.

Sensorimotor and Language

Results of a multiple linear regression analysis indicate that sensorimotor motor abilities were not found to explain a significant proportion of the variance in receptive language abilities (R = .36, R^2 = 0.11; $F(3, 50) = 2.12$; $p > .05$). See Table 4.

For expressive language, results of a multiple linear regression analysis indicate that sensorimotor motor abilities had a moderate to high effect size, that is, 42% of the variance in expressive language skills (R = .69, $R^2 = 0.42$; $F(3, 50) = 14.91$; $p < .01$) is accounted for by sensorimotor abilities. Each sensorimotor skill was then examined for individual contribution to the overall prediction of expressive language abilities. Gross motor skills were found to be significantly related to expressive language abilities ($\beta = .41$, $t(52) = 2.58$, $p = < .01$). Fine motor ($\beta = .29$, $t(52) = 1.86$, $p > .05$) and visual reception abilities ($\beta = .05$, $t(52) = .36$, $p > .05$) were not found to be significantly related to expressive language skills; however, fine motor was nearing significance ($p = .07$). See Table 4.

Table 4
Relationships between Language and Sensorimotor Skills

Predictor Variables	β	t	R	R^2	F
Receptive Language			.36	.11	2.12
Gross motor	.03	.13			
Visual reception	.16	.82			
Fine motor	.19	.94			
Expressive Language			.69	.42	14.91**
Gross motor	.41	2.58*			
Visual reception	.05	.36			
Fine motor	.29	1.86			

Note. N = 54, *$p < .05$; **$p < 0.01$.

Discussion

The results of this study support the embodied nature of sensorimotor, language, and gesture skill development. These skills all play an important role in a child's early development and are all interrelated during the infant and toddler years. These findings are of importance because they provide researchers and clinicians with further information about typical development and have the potential to impact future clinical decision making, while supporting the need for multidisciplinary assessment and intervention of children.

This study found that a combination of sensorimotor skills is related to gesture in both structured and unstructured settings thus providing a response to our first research question addressing the relationship between sensorimotor skills and gesture. Interestingly, when examining each individual sensorimotor skill, visual reception was the only skill related to gesture that reached significance in the unstructured setting ($p < .05$) and neared significance in the structured setting ($p = .08$). These results support embodiment in that visual reception abilities are related to gesture use during early childhood. This is supported by previous work on observations of the development of mimicry (Klerk et al., 2018) and goal-based tasks (Somerville et al., 2005), and may be explained by activation of the mirror neuron system when actions are observed. The finding that fine and gross motor abilities were not related to gesture was interesting because the use of gesture involves fine and/or gross motor ability. These findings could be explained by the fact that gross and fine motor skills tend to be associated with exploration in early childhood as opposed to communication (Anderson et al., 2013). Gestures are the first instance when a child can communicate and are a prerequisite to language development. Therefore, it may be that gross and fine motor abilities are more highly correlated with exploration actions during this stage of development rather than language. Meanwhile, gestures are communicative in nature which explains the correlation between language and gesture use.

The second research question addressed the relationship between sensorimotor skills and language. This study found no relationship between sensorimotor abilities and receptive language; however, sensorimotor skills explained a significant proportion of the variance in expressive language. When each sensorimotor skill was examined individually, gross motor skills were significantly correlated with expressive language ($p < 0.01$) and fine motor skills were nearing significance ($p = .07$). These findings support other research linking gross motor skills to language abilities (e.g. Iverson & Fagan, 2004; Luike et al., 2019) and fine motor skills to language abilities (Choi et al., 2018, 2019; Luike et al., 2019). Surprisingly, none of the sensorimotor skills were found to be related to receptive language especially in light of the exploratory nature established for gross and fine motor abilities (Anderson et al., 2013); however, this finding is consistent with findings from Franchini et al., 2018 examining developmental profiles of children at risk for developing ASD, which found that motor abilities are more highly related to expressive language than receptive language. This is an area in need of further exploration.

Clinical Implications

Overall, the results of this study support an embodied development perspective with sensorimotor skills relating to gesture and language development. These findings add to the large body of knowledge about typical human development and may translate to assessment and intervention procedures of children at risk of or diagnosed with poor developmental skills. These results support the need to consider the entire developmental profile of a child when determining level of functioning and in planning for assessment and intervention when necessary. Additionally, this paper is of great importance because it supports the need for complementary, interdisciplinary treatment of individuals by healthcare professionals specialized in distinct areas (e.g. speech pathology, physical therapy, and occupational therapy).

Limitations

Though the present study offers important results, it is not without limitations. The first limitation is the sample size. Although adequate for all analyses conducted, given the number of different variables investigated, a larger sample size would have provided results that are more generalizable to the population. The second limitation relates to participants. The participants in this study were homogeneous and represented primarily white, middle class families. Therefore, results of this study are also representative of these demographics and one should use caution when interpreting these results with respect to other races, cultures, and levels of socioeconomic status.

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