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Walking Ability is Associated with Social Communication Skills in Infants at High Risk for Autism Spectrum Disorder

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Abstract

Achievement of early motor milestones in infancy affords new opportunities for social interaction and communication. Research has shown that both motor and social deficits are observed in infants who later develop autism spectrum disorder (ASD). The current study examined associations between motor and social-communication skills in 12-month-old infant siblings of children with ASD who are at heightened risk for developmental delays (N=86) and low-risk, typically developing infants (N=113). Infants were classified into one of three groups based on their walking ability: walkers (walks independently), standers (stands independently), or pre-walkers (does not yet stand or walk independently). Social-communication and cognitive skills were assessed with two standardized assessments (Communication and Symbolic Behaviors Scales [CSBS] and Mullen Scales of Early Learning) and compared across the three walking groups. Results demonstrated that high-risk walkers showed superior social-communication skills, but commensurate cognitive skills, compared to high-risk pre-walkers. In contrast, social-communication and cognitive skills were largely comparable for low-risk infants, regardless of walking status. Findings suggest that for high-risk infants, who are already vulnerable to developmental delays and ASD, independent walking may facilitate the emergence of social-communication abilities. Pivotal motor milestones may serve as useful indicators of social-communication delays and targets for intervention.

Keywords

autism spectrum disorder; social-communication; walking; motor development; early identification

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Introduction

In the first two years of life, infants experience dramatic motoric transitions that support goal-oriented behavior and significantly alter their interactions with objects and people in the environment. Before the emergence of motoric control and independent locomotion, social interactions in the first months of life consist of dyadic, face-to-face play with a caregiver (Bakeman & Adamson, 1984). The achievement of reaching and grasping between 3–6 months of age facilitates object manipulation and coincides with increased joint engagement with objects and caregivers, and increased sensitivity to triadic interactions (Bakeman & Adamson, 1984; Striano & Stahl, 2005). The onset of independent locomotion, i.e. crawling, between 6- to 9-months increases opportunities for interactions with social features of the environment. Compared to pre-crawlers, infants of the same age who are given a walker to independently locomote exhibit an increase in pivotal behaviors that are essential for the emergence of language, including attention to caregivers, triadic interaction, and social referencing (Campos et al., 2000; Campos, Kermoian, & Zumbahlen, 1992; Gustafson, 1984).

Independent walking typically emerges near the end of the first year of life and is associated with a host of changes in perceptual, cognitive, and social development (Adolph & Berger, 2007). Perceptually, locomoting with an upright posture renders a newly effortless field of view during locomotion, including distal objects and caregiver faces. These changes afford significant improvement in the quality of parent-infant interactions (Kretch, Franchak, & Adolph, 2014). The onset of walking also allows infants to seek out and actively engage caregivers by directing their attention to interesting objects and events (Karasik, Tamis-LeMonda, & Adolph, 2011), leading to more frequent active bids for social interaction (Clearfield, 2011; Clearfield, Osborne, & Mullen, 2008). Independent walkers are observed to communicate more frequently with a caregiver using vocalizations and gestures, such as showing, giving, and distal pointing, leading to opportunities for rich social exchanges (Clearfield et al., 2008; Karasik et al., 2011). Mothers of infant walkers are, in-turn, more likely to respond to these social bids with action directives, providing walkers with a more enriched language environment than crawlers (Green, Gustafson, & West, 1980; Karasik, Tamis-Lemonda, & Adolph, 2014). Earlier onset of independent sitting and walking is also associated with superior expressive and receptive language skills (Libertus & Violi, 2016; Walle & Campos, 2014).

Motor Skills and Social Communication in Autism Spectrum Disorder

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized by impairments in social interaction and communication, as well as repetitive behaviors and/or restricted interests (American Psychiatric Association, 2013). While impairments in fine and gross motor skills are not considered core symptoms of ASD, they are frequently observed as associated features (Matson, Mahan, Fodstad, Hess, & Neal, 2010; Provost, Lopez, & Heimerl, 2007; see Esposito & Paşca, 2013). Some studies suggest that, compared to typically developing infants, infants who later develop ASD experience delays or abnormalities in motor development in the first year of life (Flanagan, Landa, Bhat, & Bauman, 2012; Gernsbacher, Sauer, Geye, Schweigert, & Hill Goldsmith, 2008; Ozonoff et al., 2008). Similar to typically developing infants, early motor skills in young children with ASD are associated with language development (Gernsbacher et al., 2008), in addition to face processing (Leonard, Bedford, et al., 2014), autism severity (MacDonald, Lord, & Ulrich, 2014; Matson et al., 2010), and adaptive behavior (MacDonald, Lord, & Ulrich, 2013). The onset of walking has been suggested as an especially important milestone for predicting rate of language development in children with ASD (Bedford, Pickles, & Lord, 2016).

Differences in early motor and social-communication skills have also been identified in high-risk (HR) infant siblings of children with ASD. Approximately 20% of high-risk infant siblings develop ASD and an additional 28% of siblings exhibit social-communication delays, presumably part of the “broader autism phenotype” (Ozonoff et al., 2014). Motor delays have been studied less in high-risk infants, but have the potential for broadening our understanding of the facilitative role of motor skills for social and language development. Studies that investigated motor development in high-risk infants find lower gross and fine motor skills in the first year of life (Bhat, Galloway, & Landa, 2012; Leonard, Elsabbagh, Hill, & the BASIS Team, 2014; Libertus, Sheperd, Ross, & Landa, 2014), including delayed emergence of sitting and standing postures (Nickel, Thatcher, Keller, Wozniak, & Iverson, 2013). Early motor skills in high-risk infants have also been linked to social-communication development, including babbling and gesture use (Bhat et al., 2012; LeBarton & Iverson, 2016).

The Current Study

The onset of walking significantly enhances the quality of parent-infant interactions and brings about more sophisticated social-communication skills, making it an intriguing potential early intervention target for infants at risk for ASD (Lobo, Harbourne, Dusing, & McCoy, 2013). Research thus far has not identified delays in walking for high-risk infants, but it is possible that high-risk infant walkers experience the benefits of typically developing walking infants and demonstrate enhanced social-communication skills. In other words, walking may facilitate social-communication skills for high-risk infants who are already at risk for social-communication deficits. Given the paucity of documented, effective interventions for infants in the first two years of life (Bradshaw, Steiner, Gengoux, & Koegel, 2015), an understanding of the interplay between walking and social-communication may help guide early identification and intervention efforts for ASD in infancy.

The current study investigates walking and social-communication abilities in 12-month-old infants at high and low risk for ASD. Few studies to date have examined the link between walking and social-communication skills for high-risk 12-month-old infants. Further, many investigations of walking and early social interaction and communication skills have relied on either parent-report or behavioral coding of naturalistic parent-infant interactions, rather than standardized assessments. In naturalistic parent-infant interactions, infant walkers may have more opportunities to initiate social-communicative bids due to their independent mobility (e.g., bringing an object to a caregiver), while infant pre-walkers may rely more on parent scaffolding, thus initiating fewer social bids. To assess whether the onset of walking enhances social-communication skills, and not just increases social-communication opportunities, the current study utilizes a standardized assessment designed to elicit social-communication and symbolic play skills from infants while they are in a seated position (Communication and Symbolic Behavior Scales [CSBS], Wetherby & Prizant, 2002). Evaluating infants while in the same sitting posture allows all participants equal visual and motoric access to proximal and distal objects, events, and people, regardless of walking ability. Additionally, the developmental transition from crawling to walking is typically mediated by a third motoric milestone: independent standing. In order to comprehensively examine the impact of this major developmental transition, we compared infants across three stages of motor development: pre-walkers (i.e., infants who are not yet standing or walking independently), standers (i.e., infants who are standing independently), and walkers (i.e., infants who are walking independently).

Our first aim in this study was to compare walking ability for 12-month-old infants at high risk and low risk for ASD. Because the majority of high-risk infant siblings exhibit typical development (Messinger et al., 2013), and there is currently no empirical data in the literature documenting delayed walking onset for high-risk infants as a group, we hypothesized that there would be no difference in walking ability (i.e., the proportion of pre-walkers, standers, and walkers) between the high-risk and low-risk groups. Second, we aimed to identify differences in social-communication and symbolic play skills across walking groups between high-risk and low-risk infants. We evaluated this aim in two ways. First, we compared scores on the CSBS across walking groups between high-risk and low-risk infants. Second, we compared the proportion of infants who scored in the concern range on the CSBS, which is a clinically significant predictor of a potential language disorder (Wetherby & Prizant, 2002), across walking groups between high-risk and low-risk infants. We expected that in both risk groups, walkers would exhibit superior social-communication and symbolic play skills, demonstrated by higher scores on the CSBS. In regard to differences in the proportion of infants scoring in the concern range on the CSBS, we hypothesized that a lower proportion of high-risk infant walkers, compared to high-risk standers and high-risk pre-walkers, would score in the concern range. In contrast, we expected very few low-risk infants to score in the concern range on the CSBS, and so did not anticipate associations between walking status and the proportion of low-risk infants scoring in the concern range on this measure. In order to ascertain the extent to which walking ability was associated with broad development skills, our third aim was to test the association between walking ability and cognitive and fine motor skills for high-risk and low-risk infants. We hypothesized that walking would have a unique role in promoting the development of social-communication skills, but that walking would not necessarily facilitate the development of broad cognitive or fine motor skills. We therefore expected no association between walking ability and cognitive and fine motor skills for either group.

Methods

Participants

Participants included 199 infants seen within one month of their 12-month birthday (M = 12.39 months, SD = 0.38). Infants were considered to be at either high risk (HR; N=86, 60 males) or low risk (LR; N=113, 69 males) for ASD. High-risk participants had an older full-biological sibling with ASD that was confirmed through a diagnostic evaluation report signed by a licensed clinical or school psychologist or a medical doctor. Diagnoses were further confirmed by clinical review of the evaluation reports and scores within the ASD range on the Social Responsiveness Scale (Constantino, 2012) and the Social Communication Questionnaire (Rutter, Bailey, & Lord, 2003). Low-risk participants had no familial history of ASD in first- or second-degree relatives. Exclusion criteria for both high-risk and low-risk infants included gestational age below 35 weeks, major hearing and/or visual impairment, non-febrile seizure disorders, known genetic syndrome, and significant pre- or perinatal complications. Families were recruited through local pediatric practices, hospitals, OB/GYN offices, radio and media ads, and state and local autism organizations. Written, informed consent was obtained from a parent or guardian of each child before any assessment or data collection. All procedures involving human subjects in this study were approved by the Institutional Review Board (IRB) of Emory University School of Medicine.

Procedures

The data reported here are a subset of a large longitudinal study in which infants were seen at 12-months for a one day evaluation consisting of the Communication and Symbolic Behavior Scales (Wetherby & Prizant, 2002) and the Mullen Scales of Early Learning (Mullen, 1995). All study visits began with the CSBS, which takes approximately 30-minutes to complete, followed by an approximate 20–30 minute break. The Mullen was then administered and typically lasted for 20–30 minutes. Infants were seated in a hook-on high chair attached to a full-sized table with a parent seated next to them for the duration of both assessments. The Gross Motor domain of the Mullen was administered on the floor.

The CSBS was administered by licensed speech-language pathologists (SLPs) with expertise in infant development and ASD. All SLPs were trained by an author of the CSBS (A. Wetherby) to 90% reliability in administration and scoring. Training and reliability monitoring occurred through bi-weekly meetings for two years that involved review of videos and discussion of administration and scoring issues. The Mullen was administered by licensed psychologists with expertise in infant development and ASD, or a doctoral psychology trainee supervised by a licensed psychologist. Psychologists and trainees were blind to the risk status of the participant and to the exact aims of the present study.

Measures

The Mullen Scales of Early Learning (Mullen) is a standardized developmental measure designed for children from birth to 68 months. It provides t-scores and age equivalences for five domains of development: Visual Reception, Gross Motor, Fine Motor, Receptive Language, and Expressive Language. T-scores have a mean of 50 and standard deviation of 10. Corrected age was used to calculate t-scores for infants younger than 37 weeks. For the purpose of the present study, infant walking status was assessed using two items from the Gross Motor domain: *Stands Alone* and *Walks Alone*. If an infant scored zero (does not demonstrate the skill) on both items, the participant was classified as a 'pre-walker'. If an infant was given a score of one (demonstrates the skill) for *Stands Alone* and a zero for *Walks Alone*, the participant was categorized as a 'stander'. Finally, if an infant was given a score of one on both *Stands Alone* and *Walks Alone*, the participant was classified as a 'walker'.

The Communication and Symbolic Behavior Scales – Developmental Profile, Behavior Sample (CSBS) is a standardized early childhood communication play-based assessment for infants and toddlers. The assessment includes 20 individual items that make up seven clusters that go into three composite domains (Social, Speech, and Symbolic) and culminate in a Total score. For the purpose of this study, we include all 20 individual item raw scores, all seven cluster scores, and the CSBS total score in our analyses. Raw scores generally reflect the number of activities in which an infant exhibited a particular behavior, with a minimum of 0 and a maximum of 6, unless otherwise noted below. Cluster scores are represented in scaled scores (mean of 10, standard deviation of 3) and the Total score is represented by a standard score (mean of 100, standard deviation of 15). The criterion level for concern is based on performance on the CSBS of at least 1.25 standard deviations below the mean on the composite and total scores (Wetherby & Prizant, 2002). That is, a score ≤6 for composites and clusters (described below) and a CSBS total score ≤81 is considered a score below average and in the concern range. Because all infants, including those born < 37 weeks were at least 11-months corrected age and there are no CSBS norms for infants younger than 12-months of age, we used chronological age to calculate cluster and composite scores for all infants.

The Social composite includes the Emotion and Eye Gaze, Communication, and Gestures clusters. The Emotion and Eye Gaze cluster includes 3 items: *gaze shifts* (alternating eye gaze between a person and an object and person), *shared positive affect* (directed large, joyful smiles), and *gaze/point following* (i.e., response to joint attention; the child's response to two opportunities to follow another person's gaze and distal point; this item has a maximum score of 2). The Communication cluster includes 4 items measuring the frequency and purpose of communicative acts across activities. A communicative act, by definition, must be a gesture, vocalization, or verbalization that is directed toward another person and serves a communicative function. The 4 items that make up the Communication cluster include: *communication rate* (frequency of communicative acts in each of the six activities; maximum score of 18), *behavior regulation* (requesting or protesting), *social interaction* (initiating a social routine, greeting, showing off), and *joint attention* (directing caregiver/examiner's attention to something of interest). The Gestures cluster includes 2 items: the *inventory of conventional gestures* (e.g., giving, showing, pointing, etc.) and *distal gestures* (frequency of distal gestures).

The Speech composite includes the Sounds and Words clusters. The Sounds cluster includes 2 items: *syllables with consonants* (frequency of using a syllable with a consonant) and *inventory of consonants* (variety of consonants). The Words cluster includes 4 items: *words* (frequency of the use of words directed to the examiner or caregiver for a communicative purpose), *inventory of words* (capturing the variety of words), *word combinations* (frequency of combining 2 or more words), and *inventory of word combinations* (variety of word combinations).

The Symbolic composite includes the Understanding and Object Use clusters. The Understanding cluster includes 1 item: *language comprehension* (identification of eight familiar objects, people in the room, and body parts). The Object Use cluster uses a symbolic play probe to score 4 items: *inventory of action schemes* (e.g., stirring or pouring; maximum score of 12), *action schemes toward other* (e.g., feeding caregiver with a spoon), *sequences in action schemes* (using multiple action schemes together), and *stacks tower of blocks*.

Statistical Methods

Data analyses were performed using SAS v.9.4 (Cary, NC). Demographics were calculated by walking status, within high and low risk categories, using means and standard deviations for continuous variables and frequencies and percentages for categorical variables. Demographic characteristics were statistically assessed for differences across walking status groups, within ASD risk categories, using one-factor analysis of variance (ANOVA) for continuous variables and Chi-square tests of independence or Fisher's exact tests for categorical variables. Fisher's exact tests were used in place of Chi-square tests when expected frequency counts were low (<5). When significant, post-hoc tests were evaluated, either Tukey-Kramer or Holm method adjustments were used.

First, a global test of association between walking status (pre-walkers, standers, walkers) and ASD risk groups (high, low) was calculated via a Chi-square test of independence. Second, to test for statistical differences in social-communication and play skills across walking groups (pre-walkers, standers, and walkers), between risk group (high-risk versus low-risk), two-factor ANOVA was employed with walking group and risk status as the main effects. A walking group by risk status interaction was further included in each of these regression models. To control for the effects of physical maturation on variables of interest, especially walking ability, age was added as an adjusting covariate in each of the ANOVA models. Significant two-factor interactions were evaluated at α=0.1 significance level, with all subsequent results considered at α=0.05.

Significant interactions identified in the two-factor ANOVAs were further probed, within each risk group, using age-adjusted one-factor ANOVA. In all two-factor and one-factor ANOVA models, walking group variances were modeled separately, to account for factor-level heterogeneity, and estimated with the Satterthwaite denominator degrees of freedom method. One-factor ANOVA results are given as means and standard error.

Similar to the aforementioned ANOVA approach, we also compared participants scoring in the concern range at ≤6 versus >6 for CSBS composites and clusters, and ≤81 versus >81 for the CSBS total score across walking groups, between high-risk and low-risk infants using age-adjusted logistic regression models. Significant two-factor interactions were evaluated at α=0.1 significance level. Significant interactions identified in the logistic regression models were further probed, within each risk group, using Chi-square tests of independence, run separately for high-risk and low-risk infants.

Finally, in order to test for an association in cognitive and fine motor skills, with walking ability and ASD risk categories, both two-factor and one-factor ANOVA models were considered, but did not produce significant findings.

Results

Demographic characteristics of all participants separated by risk and walking status are presented in Table 1. Within the high-risk group (N=86), 24 were pre-walkers (28%), 27 were standers (31%), and 35 walkers (41%). Within the low-risk group (N=113), 36 were pre-walkers (32%), 29 were standers (26%), and 48 were walkers (42%). There were no significant differences between pre-walkers, standers, and walkers within each of the high and low-risk groups on any of the following demographic variables: sex, parental education, gestational age, and race. There was a significant difference in chronological age for the high-risk group ($F_{2,56}$=3.36, p = 0.042) and a marginally significant difference in the low-risk group ($F_{2,68}$=2.88, p = 0.063). On average, high-risk walkers were approximately six days older than standers and pre-walkers. As noted in the statistical methods, all analyses were age-adjusted to account for maturation.

Our first aim was to evaluate walking abilities in infants at high and low risk for ASD. There were no differences in the proportion of pre-walkers, standers, and walkers between high-risk and low-risk groups ($\chi^2(2)$ = 0.86, p = 0.651). Second, we evaluated differences in social-communication and play skills across walking groups (pre-walkers, standers, and walkers) between ASD risk status (high-risk versus low-risk). Results of the age-adjusted, two-factor analysis of variance are presented in Figure 1. Significant walking status by risk interactions were demonstrated for the following CSBS variables: Communication Rate (p = 0.042), Words (p = 0.015), Object Use cluster (p = 0.048), Gestures cluster (p = 0.010), and Inventory of Action Schemes (p = 0.040). Additionally, the following variables were approaching a significant interaction, based on p < 0.1: Behavior Regulation (p=0.068), Inventory of Gestures (p = 0.093), and Distal Gestures (p = 0.082).

Age-adjusted one-factor ANOVAs for all variables in which the interaction p-value was less than 0.1 were then run separately for high-risk and low-risk groups to identify significant differences, based on walking status (see Table 2). Analyses revealed that for high-risk infants, there were significant differences in the frequency of requesting and protesting (Behavior Regulation, p = 0.009), use of gestures (Gestures cluster, p = 0.012; Distal Gestures, p = 0.008), word use (Words, p = 0.006), and symbolic play (Object Use cluster, p < 0.001; Action Scheme, p = 0.003). Pairwise comparisons show that compared to high-risk walkers, high-risk pre-walkers exhibited significantly fewer skills in requesting/protesting and gesture use. Compared to both high-risk walkers and standers, high-risk pre-walkers exhibited significantly fewer play skills. Finally, both high-risk pre-walkers and standers had significantly fewer words than high-risk walkers. In contrast, these social-communication and play skills did not differ significantly for low-risk infants (see Table 2b).

Logistic regression was used to assess whether walking ability affected the number of infants in the concern range (see Fig. 2). Significant interactions were detected for the Communication cluster (p = 0.008) and marginally significant interactions were observed for the Object Use cluster ($p = 0.051$) and the Total Score ($p = 0.094$). Chi-square tests of independence (see Table 3) revealed that for high-risk infants, a significantly higher proportion of pre-walkers scored in the concern range for the Communication Cluster ($p = 0.011$), Object Use cluster ($p = 0.004$), and the CSBS Total score ($p = 0.030$). Walking status was not associated with scores in the concern range for low-risk infants (see Table 3b).

In a final analysis, we compared infant walking status to other areas of development in order to test whether the associations between walking and social-communication could be explained by developmental level. Walking status was not associated with Mullen Visual Reception skills ($F_{2, 139} = 0.29$, $p = 0.746$), a measure of nonverbal cognitive ability, or Fine Motor skills ($F_{2, 136} = 0.14$, $p = 0.865$) for all infants and when analyzed separately by risk status.

Discussion

This investigation demonstrates that the achievement of walking is a pivotal milestone associated with superior verbal and nonverbal social-communication skills for infants at high risk for ASD. We found that the proportion of walkers was comparable among 12-month-old high-risk and low-risk infants suggesting that high-risk infants, as a group, did not experience delayed onset of walking. High-risk infants who were walking used more gestures, requests, and protests during a standardized social-communication assessment compared to high-risk pre-walkers. A significantly higher proportion of high-risk walkers used at least one word during the exam compared to both standers and pre-walkers. Finally, both high-risk walkers and standers exhibited more sophisticated symbolic play skills than pre-walkers. In contrast, low-risk infant walkers did not differ on any measures of social-communication or play skills compared to low-risk standers or pre-walkers.

In order to evaluate the clinical significance of these results, we also examined differences in the proportion of walkers, standers, and pre-walkers who scored in the concern range on the CSBS, across risk status. High-risk infants who were not yet standing or walking exhibited scores in the concern range for the Communication cluster, Object Use cluster, and the CSBS Total score. In contrast, low-risk infants did not differ on scores in the concern range based on their walking status. These results confirm that the lower social-communication scores observed in high-risk infant pre-walkers are clinically significant and suggests that these infants may be at a higher risk for social-communication delays.

The finding that walking status has little to no impact on low-risk infants' performance on a standardized measure of social-communication is somewhat surprising in light of previous research on typically developing infants (e.g., Clearfield, 2011). Our study differs from prior research in our measure of social-communication. The CSBS is designed to evaluate predictors of language for the purpose of screening and identifying children with communicative and developmental disabilities. It is possible that most low-risk 12-month-old infants use high-quality communication with such high frequency during a structured assessment, that this measure does not capture sufficient variability to detect the facilitative effects of walking. In other words, low-risk infants in this study may have exhibited a "ceiling" effect on this measure because they were not at-risk for developmental delays. Our study did not allow us to evaluate the effect of independent mobility (i.e., crawling) because all high-risk and low-risk infants were crawling at 12-months of age. We also did not collect information on the precise onset of walking for infants, and thus cannot determine whether experience with walking (e.g., 1 day vs. 1 month of walking experience) affected social-communication abilities. It is possible that such analyses would shed light onto the lack of differences observed in the low-risk group.

In contrast, for infants who are already vulnerable to social and communication delays, walking may actually facilitate the development of social-communication. Some have suggested that independent locomotion, which most often begins with crawling, is the setting event for a cascade of social-communicative abilities (Campos et al., 2000). It is possible that this control parameter may manifest differently for high-risk infants and that either more locomotor experience, or a more sophisticated form of locomotor experience (i.e., walking), is required for dramatic changes in social-communication.

Few studies have included standing as a third stage amid the transition from crawling to walking. These results suggest that although standers were not statistically distinguished from both pre-walkers and walkers in any of our analyses, there remained a stepwise increase in skills as infants progressed to independent walking. Standing could be further explored as an intermediary stage in this motoric transition. Additionally, this is the first study to our knowledge that demonstrates an association between walking and symbolic play skills. The onset of walking has been associated with significant increases in language (Walle & Campos, 2014) and the present study demonstrates that for high-risk infants it is also associated with increases in symbolic play, a predictor of language development.

Symbolic representation is an important prerequisite for the development of communication, and symbolic play is a strong predictor of language (McCatreh, Warren, & Yoder, 1996; Lyytinen, Laakso, Poikkeus, & Rita, 1999). Children with language delay and autism spectrum disorder also experience impaired symbolic play skills. Many studies have demonstrated that advancements in symbolic play are closely aligned with advancements in language (e.g., McCune, 1995), raising the possibility of shared underlying mechanisms. Some have suggested that symbolic representation and language emerge from the capacity for mental representation (McCune, 1995) and from social interaction with a caregiver and shared intentionality (Striano et al., 2001; Rokaczy, Tomasello, & Striano, 2005). Imitation skills, also critical for symbolic play, are similarly tied to mental representation and intention understanding. Previous research has shown that the onset of walking is associated with behaviors indicative of shared intentionality, such as initiation of joint attention (Karasik, Tamis-LeMonda, & Adolph, 2011), and it is possible that this mechanism is related to the association between symbolic play and walking ability observed here. That is, as walking leads to increased frequency of triadic social interactions, infants gain more opportunities to imitate and engage in shared intentionality with a caregiver, allowing for earlier emergence of symbolic play skills. Additionally, there is some evidence to suggest that visual object recognition, including recognition of multiple views of an object, is associated with some types of symbolic play (Smith and Jones, 2011). The expanded perceptual world of an infant who has started walking may serve to improve the infant’s visual object recognition and thus symbolic play skills.

In this study, it remains unknown how walking ability uniquely contributed to the development of symbolic play, gestures, and language, all of which were significantly more robust in high-risk infant walkers compared to high-risk standers and/or pre-walkers. Research suggests that symbolic play precedes the emergence of first words, and so it is uncertain whether walking supports the development of mental representation and symbolic play, which in turn facilitate the emergence of language. Or whether walking supports shared intentionality, which, as stated above, may contribute to the emergence of all three skills: symbolic play, gestures, and language.

An age-held constant design was used for these analyses, and fine motor and nonverbal cognitive abilities did not differ across pre-walkers, standers, and walkers for both high-risk and low-risk infants. Thus, it is unlikely that observed differences in social-communication abilities were due to chronological age or developmental level.

Limitations

Study findings would be strengthened with a longitudinal design in which infant social-communication skills are evaluated in each stage of motoric development. Our high-risk infant walkers were significantly older than pre-walkers, and a similar, non-significant trend was observed for the low-risk group. In spite of this limitation, we accounted for the small difference in age (walkers were approximately six days older than pre-walkers) by using age-adjusted analyses. Additionally, this study lacks information on the exact age of onset for independent walking and so we cannot evaluate whether high-risk infants experienced a mild delay in the onset of walking, nor can we examine if the amount of walking experience was also associated with social-communication skills. It would be useful to compare a standardized measure of social-communication to behavioral coding of naturalistic interactions in order to confirm and replicate previous findings that walking onset is associated with social-communication for typically developing infants. Although our high-risk and low-risk groups had comparable demographic characteristics, the majority of our sample as a whole was restricted to highly educated, White families, limiting the generalizability of our findings. Our study design included six late preterm infants born between 35–37 weeks gestation (1 high-risk and 5 low-risk) whose CSBS scores could not be corrected due to the lack of CSBS norms for 11-month-old infants. This is a very small proportion of our sample and most of our significant findings were in the CSBS raw scores, for which gestational age would not be taken into account. Although it is unlikely that including these late preterm infants had an effect on our overall findings, it is important to note this as a potential limitation of this study.

Future Directions

Future research should continue to identify how, and at what point in development, motor milestones are associated with superior social-communication skills. The current study focused on walking as a pivotal motoric achievement, yet other milestones, including sitting, reaching, and grasping, may be similarly important in early development. Investigating the timing of these motoric advancements in a high-risk sample, and the implication of achievement for other developmental domains, will further our understanding of the relationship between motor and social development in the context of ASD. In this regard, research aimed at identifying the neurological underpinnings of these associations may help to shed light on the neural mechanisms associated with the emergence of ASD and language disorders.

Although we did not document that 12-month-old high-risk infants are delayed in walking, our findings extend previous research that motor abilities in ASD may be associated with communication abilities (e.g., Bhat et al., 2012). This has implications for consideration of motor skills in the early identification of language and social disabilities, and for early intervention strategies. It is important to consider how walking might result in significant jumps in social-communication skills, regardless of age and overall developmental level. It could be that walking affords new embodied experiences, including new visual perspective or more efficient locomotion between objects of interest and caregivers, that make social-communication increasingly motivating. In which case, early intervention should consider the infant's visual and motoric experience of the world and modify accordingly. Alternatively, it is possible that increased social motivation contributes to walking onset and so infant walkers are already likely to have more advanced social-communication skills. Motor development and its impact on reorganization of the infant social and interactive experience should be considered in light of early identification and intervention efforts for ASD.

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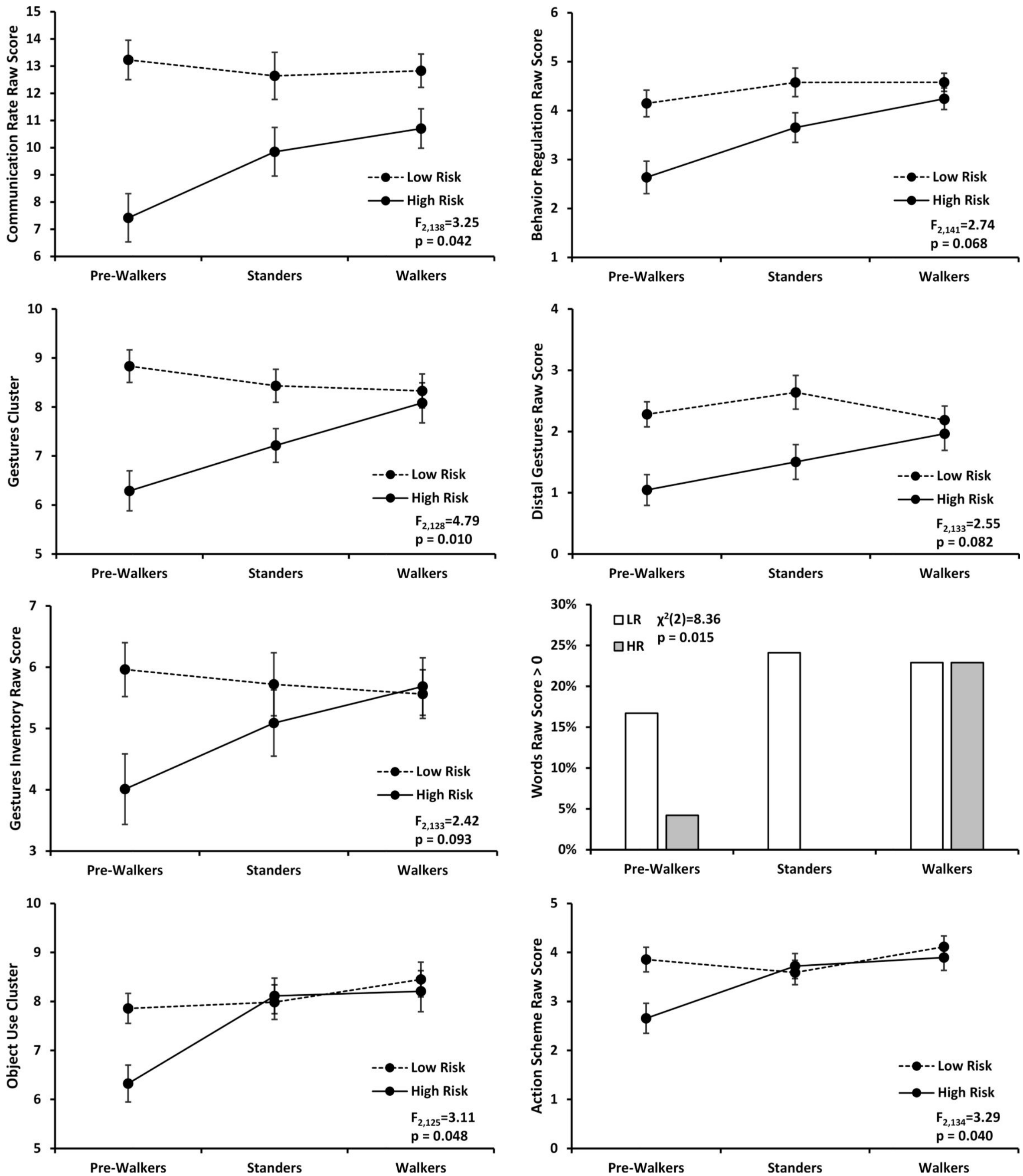

Figure 1.

Significant two-way interaction plots (ANOVA and logistic) between walking status (pre-walkers, standers, walkers) and risk category (high risk versus low risk). All analyses were age-adjusted significance was evaluated at $\alpha<0.1$. P-values indicate significant interactions between risk status and walking status.

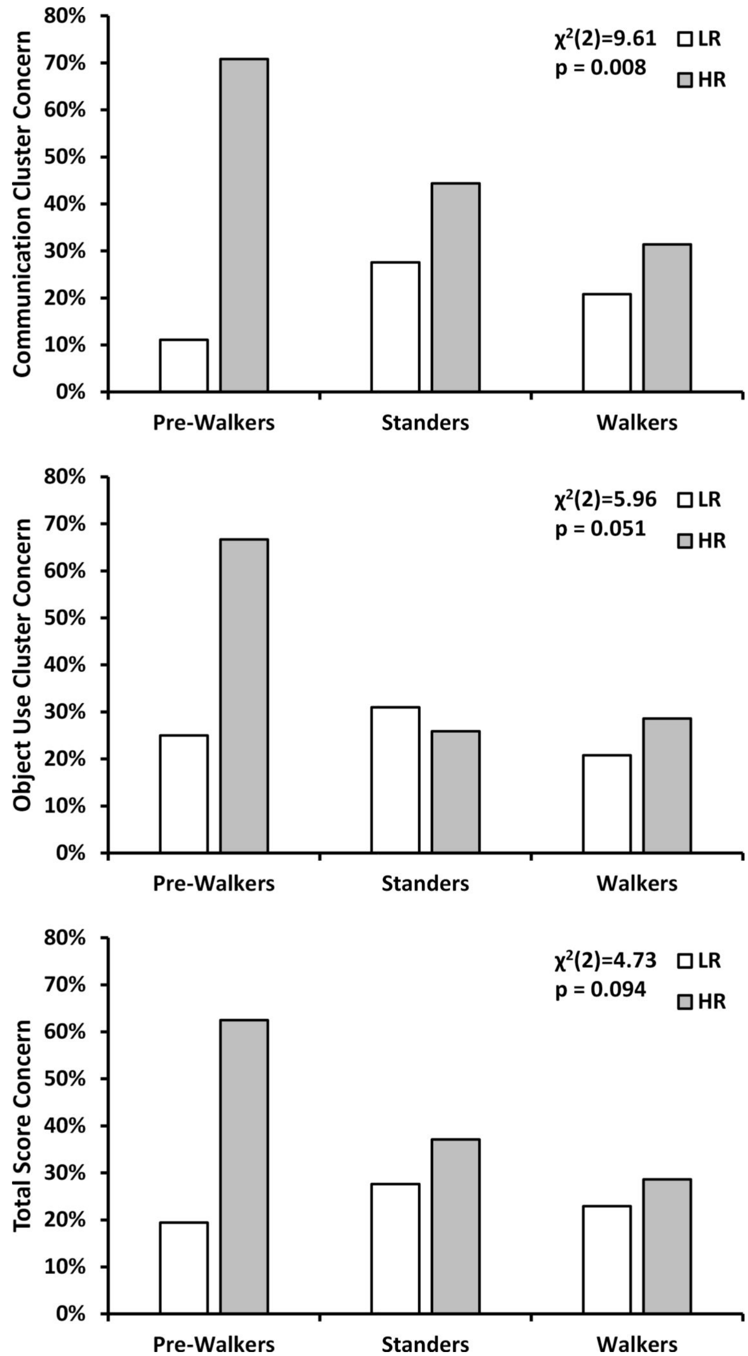

Figure 2.

Significant two-way interaction plots (logistic) between walking status (pre-walkers, standers, walkers) and risk category (high versus low), age-adjusted, significant at $\alpha<0.1$.

Table 1

Participant Demographics across High-Risk and Low-Risk Infants

Characteristic, N (%)	High Risk					Low Risk				
	Pre-Walkers N=24	Standers N=27	Walkers N=35	Statistic	P-Value	Pre-Walkers N=36	Standers N=29	Walkers N=48	Statistic	P-Value
Gender										
Female	8 (33.3%)	11 (40.7%)	7 (20%)	$\chi^2(2)=3.26$	0.196	15 (41.7%)	10 (34.5%)	19 (39.6%)	$\chi^2(2)=0.36$	0.834
Male	16 (66.7%)	16 (59.3%)	28 (80%)			21 (58.3%)	19 (65.5%)	29 (60.4%)		
Age (mos), Mean ± SD[1]	12.29 (0.31)	12.37 (0.40)	12.54 (0.45)	$F_{2,56}=3.36$	**0.042**	12.32 (0.28)	12.29 (0.27)	12.47 (0.42)	$F_{2,68}=2.88$	0.063
Gestational Age (weeks)	38.86 (1.65)	38.48 (1.54)	39.32 (1.48)	$F_{2,77}=2.17$	0.121	38.92 (1.56)	39.54 (1.30)	38.95 (1.30)	$F_{2,105}=1.89$	0.157
Parent Education Level[2]										
Less than College	5 (20.8%)	4 (14.8%)	11 (31.4%)	$\chi^2(4)=2.76$	0.599	2 (5.6%)	0 (0%)	3 (6.3%)	TP=0.003	0.784
College Graduate	13 (54.2%)	16 (59.3%)	15 (42.9%)			9 (25%)	9 (31%)	12 (25%)		
Post College	6 (25%)	7 (25.9%)	9 (25.7%)			25 (69.4%)	20 (69%)	33 (68.7%)		
Race[2]										
White	18 (75%)	22 (81.5%)	21 (60%)	TP = 0.001	0.245	32 (88.9%)	24 (82.8%)	42 (87.5%)	TP=0.001	0.183
African-American	5 (20.8%)	2 (7.4%)	9 (25.7%)			2 (5.6%)	0 (0%)	4 (8.3%)		
Other[3]	1 (4.2%)	3 (11.1%)	5 (14.3%)			2 (5.6%)	5 (17.2%)	2 (4.2%)		
Asian	0 (0%)	0 (0%)	0 (0%)			0 (0%)	1 (20%)	1 (50%)		
Multiracial	1 (100%)	3 (100%)	4 (80%)			2 (100%)	4 (80%)	1 (50%)		
Did Not State	0 (0%)	0 (0%)	1 (20%)			0 (0%)	0 (0%)	0 (0%)		

[1] Pairwise comparisons indicated pre-walkers as significantly younger than walkers; pairwise adjustments made using the Tukey-Kramer method.

[2] Fisher's exact tests were used for Low Risk Parent Education and both risk groups for Race because the expected frequency counts were less than 5. The statistics reported are Table Probabilities (TP) based on Fisher's exact test.

[3] A Chi-squared test was used to test for differences in racial group across pre-walkers, standers, and walkers in HR and LR groups. Due to the low number of participants who identified their race as Asian, Multiracial, or did not state, these three groups were combined into the group "Other" for the statistical test. However, the breakdown of participants in the Other group is listed underneath as the number of participants and the percent of "Other" within each walking group (e.g., 100% of the Other racial group for HR Pre-Walkers identified as Multiracial).

Table 2

Age-Adjusted One-Way ANOVAs for High-Risk (a) and Low-Risk (b) Infants across Pre-walkers, Standers, and Walkers for Measures with Significant Two-Way Interactions

a) High-Risk Infants

CSBS Item	CSBS Composite	Mean Score (SE) Pre-Walkers (a) N=24	Standers (b) N=27	Walkers (c) N=35	Test Statistic	p-value	Pairwise Comparison
Communication Rate	Social	7.59 (1.00)	9.95 (0.99)	10.66 (0.78)	$F_{2,59}$=2.94	0.061	NS
Behavior Regulation	Social	2.71 (0.39)	3.69 (0.35)	4.21 (0.26)	$F_{2,60}$=5.13	**0.009**	**a < c**
Gestures Cluster	Social	6.20 (0.47)	7.20 (0.34)	8.22 (0.44)	$F_{2,58}$=4.79	**0.012**	**a < c**
Distal Gestures	Social	0.98 (0.22)	1.49 (0.25)	2.06 (0.25)	$F_{2,56}$=5.21	**0.008**	**a < c**
Gestures Inventory	Social	3.90 (0.64)	5.06 (0.54)	5.82 (0.53)	$F_{2,55}$=2.57	0.086	NS
Words*	Speech	1 (4.2%)	0 (0%)	8 (22.9%)	TP=0.001	**0.006**	**a,b < c**
Object Use Cluster	Symbolic	6.34 (0.35)	8.14 (0.40)	8.26 (0.42)	$F_{2,55}$=8.39	**<0.001**	**a < b,c**
Action Scheme	Symbolic	2.64 (0.29)	3.72 (0.25)	3.95 (0.24)	$F_{2,59}$=6.31	**0.003**	**a < b,c**

b) Low-Risk Infants

CSBS Item	CSBS Composite	Mean Score (SE) Pre-walkers (a) N=36	Standers (b) N=29	Walkers (c) N=48	Test Statistic	p-value	Pairwise Comparison
Communication Rate	Social	13.13 (0.66)	12.51 (0.78)	12.86 (0.59)	$F_{2,77}$=0.18	0.832	NS
Behavior Regulation	Social	4.11 (0.24)	4.53 (0.24)	4.60 (0.16)	$F_{2,79}$=1.51	0.228	NS
Gestures Cluster	Social	8.86 (0.29)	8.50 (0.33)	8.22 (0.32)	$F_{2,73}$=1.11	0.335	NS
Distal Gestures	Social	2.30 (0.22)	2.68 (0.30)	2.11 (0.24)	$F_{2,77}$=1.08	0.346	NS
Gestures Inventory	Social	6.00 (0.41)	5.79 (0.50)	5.47 (0.36)	$F_{2,77}$=0.48	0.621	NS
Words*	Speech	6 (16.7%)	7 (24.1%)	11 (22.9%)	TP=0.032	0.703	NS
Object Use Cluster	Symbolic	7.85 (0.33)	7.99 (0.32)	8.39 (0.35)	$F_{2,70}$=0.67	0.513	NS
Action Scheme	Symbolic	3.86 (0.26)	3.60 (0.26)	4.08 (0.24)	$F_{2,75}$=0.89	0.415	NS

Note: One-way analyses were run only for dependent measures with significant two-way interactions (two-way interactions depicted in Figure 1). All analyses are age-adjusted, except for Words Raw Score, which was dichotomized for 0 (no words) and >0 (at least one word). Significant differences are presented in **bold**. P-values for continuous pairwise comparisons were adjusted using the Tukey method; a Holm adjustment was made for Words Raw Score. Significant pairwise comparisons are shown in the last column of each table and where walking groups are represented by letters: (a) pre-walkers, (b) standers, and (c) walkers. Pairwise adjustments made using the Tukey-Kramer method.

[*] Due to limited language of 12-month-old infants, the Words item is represented by the percent of infants who demonstrated at least one word.

Table 3

Chi-Square Tests of Independence for the Percent of Infants in the High-Risk (a) and Low-Risk (b) Groups Scoring in the Concern Range across Pre-walkers, Standers, and Walkers for Measures with Significant Two-Way Interactions

a) High-Risk Infants

CSBS Item	CSBS Composite	Pre-Walkers (a) N=24	Standers (b) N=27	Walkers (c) N=35	Test Statistic	p-value	Pairwise Comparison
Communication Cluster	Social	17 (70.8%)	12 (44.4%)	11 (31.4%)[2]	$X^2(2)=8.95$	**0.011**	**a > c**
Object Use Cluster	Social	16 (66.7%)	7 (25.9%)	10 (28.6%)[2]	$X^2(2)=11.32$	**0.004**	**a > b,c**
Total Score	Social	15 (62.5%)	10 (37.1%)	10 (28.6%)[2]	$X^2(2)=7.01$	**0.030**	**a > c**

b) Low-Risk Infants

CSBS Item	CSBS Composite	Pre-walkers (a) N=36	Standers (b) N=29	Walkers (c) N=48	Test Statistic	p-value	Pairwise Comparison
Communication Cluster	Social	4 (11.1%)	8 (27.6%)	10 (20.8%)	$X^2(2)=2.88$	0.237	NS
Object Use Cluster	Social	9 (25.0%)	9 (31.0%)	10 (20.8%)	$X^2(2)=1.01$	0.603	NS
Total Score	Total	7 (19.4%)	8 (27.6%)	11 (22.9%)	$X^2(2)=0.60$	0.740	NS

Note: One-way analyses were run only for dependent measures with significant two-way interactions (two-way interactions depicted in Figure 2). Significant differences are presented in **bold.** Significant pairwise comparisons are shown in the last column of each table and where walking groups are represented by letters: (a) pre-walkers, (b) standers, and (c) walkers. Pairwise adjustments made using the Holm method.