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Temporal-spatial gait parameters and neurodevelopment in very-low-birth-weight preterm toddlers at 18–22 months

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ABSTRACT

Children born preterm with very-low birth-weight (VLBW) have increased risk of motor impairment. Early identification of impairment guides treatment to improve long-term function. Temporal-spatial gait parameters are an easily-recorded assessment of gross motor function. The objective of this study was to characterize preterm toddlers' gait and its relationship with neurodevelopment. Velocity, cycle time, step width, step length and time asymmetry, %stance, %single-limb support, and %double-limb support were calculated for 81 VLBW preterm and 43 typically-developing (TD) toddlers. Neurodevelopment was assessed with Bayley Scales of Infant Development-3rd Edition (BSID-III) motor composite and gross motor scores. Mean step width (p = .009) was wider in preterm compared to TD toddlers. Preterm toddlers with <85 BSID-III motor composite scores, indicating mild-to-moderate delay, had significantly increased step width, step length asymmetry, and step time compared to TD toddlers. Step time was also significantly longer for lower-scoring compared to higher-scoring (≥85 BSID-III motor composite scores) preterm toddlers, suggesting that step time may be particularly sensitive to gradations of motor performance. Velocity, cycle time, step length asymmetry, %stance, step length, and step time significantly correlated with BSID-III gross motor scores, suggesting that these parameters may be revealing of gross motor function. The differences in gait between lower-scoring preterm toddlers and TD toddlers, together with the correlations between gait and BSID-III motor scores, suggest that temporal-spatial gait parameters may be useful in building a clinically-relevant, easily-conducted assessment of toddler gross motor development.

1. Introduction

Children born preterm with very-low birth-weights (VLBW) experience elevated risk for neurodevelopmental impairments, including reduced gross motor function. Cerebral palsy, the most common childhood disability [1], occurs in approximately 15% of this population, a prevalence 50 times higher than in the general population [2,3]. Developmental coordination disorder, a milder coordination impairment which nevertheless interferes with daily-living activities [4], presents in an additional 40% of VLBW preterm children [5]. Reliable identification of children at risk of impairments may be crucial to improving long-term function, yet misdiagnosis of even relatively severe motor impairment, such as cerebral palsy, is common for children younger than 18 months [6–8].

Identification and prognosis of motor impairment in toddler-aged children is primarily based on clinical exam and motor milestone history. Clinical exams typically include qualitative assessments of tone, posture, and reflexes; motor milestone history is by parental report [9]. These assessments yield poor specificity; in one study, half of diagnoses of cerebral palsy made by 12 months were retracted by the time the children were 7 years old [8]. Motor milestone assessments are made challenging by variability in parental report [10] and the wide age range in which milestones are typically attained; for example, while the average age of independent walking was found to be 12.1 months, the standard deviation was 1.8 months and 10% of apparently-healthy term-born children do not walk until 14.4 months or later [11]. Furthermore, delays in motor milestones could be confounded by cognitive development [12]. A promising observational approach

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not yet in common clinical practice is the assessment of general movements. Although assessing general movements requires a trained expert, serial examination of preterm infants at 12 months yielded 95% sensitivity and 70% specificity for predicting cerebral palsy [13].

Standardized gross motor assessments are usually designed for older children, or for children with known motor impairments [14]. For example, the Movement ABC is a reliable motor test, but is not appropriate for children <4 years old [15]. The Alberta Infant Motor Scale is designed for younger children, up to walking onset; it is inappropriate for independently-walking toddlers [16]. The GMFM, GMFCS and MAT are evaluations of motor function appropriate for toddler-aged children, but only those who have already been diagnosed with cerebral palsy; these assessments are not intended to identify motor problems [14,17–19].

Although not as common as physical exam and milestone history, the Peabody Developmental Motor Scale-2 (PDMS-2) and the Bayley Scales of Infant Development-3rd Edition (BSID-III) are also used clinically [20–22]. Both tests were designed to assess neurodevelopment in young children, and both are appropriate for detecting motor impairment in toddler-aged children. The PDMS-2 assesses motor skills exclusively, while the BSID-III has sections for cognitive, language, and motor development. The PDMS-2 can be used to detect impairment, but is primarily for measuring functional change; the BSID-III, by contrast, is explicitly discriminative and should not be used serially to measure functional change [14]. Both tests involve using props to coax children into revealing their competencies, which are evaluated—although often subjectively—by an examiner. The BSID-III requires less equipment and time to administer than the PDMS-2, although the full test is nevertheless lengthy at ~90 min [21,22]. Both tests exhibit good reliability and consistency. More at-risk children aged 1-26 months were identified as experiencing significant delay on the BSID-III than on the PDMS-2, suggesting that the BSID-III may provide more sensitive detection [21]. The BSID-III may be preferred over the PDMS-2 when Type I errors, failing to identify children with impairments, are of concern. These identifications have clinical consequences in the referral of services.

In addition to gross motor assessment, walking specifically has been studied in toddler-aged children. Until recently, study was limited to velocity and parameters which can be assessed with video and simple spatial methods, such as ink footprints on paper walkways [23]. With the advance of technology, temporal-spatial parameters can be derived from instrumented walkways. Kinematics and kinetics can be calculated with 3D-motion-capture and force plates in the gait lab, although this is less common due to the physical and temperamental limitations of toddlers.

Toddler walking is variable and expressive; however, some walking characteristics have been gleaned. Early on, experience dominates: there is a period of rapid change which levels off after the first two months of independent walking [23,24]. Toddlers' most consistent, "best effort," walking appears to occur at their highest walking velocities [25]. Walking velocity varies widely, but averages approximately 80 cm/s [25–28]. By 18 months, a majority of TD toddlers have heel-first initial contact, although flat-foot or fore-foot contact is more common in younger toddlers [29]. External hip rotation, which is present at birth, is still exhibited during walking until past toddlerhood [29].

In toddlers born preterm, walking is generally characterized as being delayed and qualitatively less coordinated [30–34]. Onset of walking for toddlers born at ≤32 weeks gestational age (GA) varies, and has been reported as similar to term-born peers [35] and as delayed by 2 months [30]. Quantitative studies are limited and few differences in gait characteristics have been reported. At 18 months of age, preterm toddlers exhibited shorter stride lengths than full-term peers; there was a trend for lower walking velocity, but it was not significant, and single-limb support (SLS) was essentially the same [32]. Step width and double-limb support (DLS) in toddlers born preterm does not appear to have been reported in the literature.

The present study reports temporal-spatial gait parameters in TD and preterm toddlers by both age and walking experience. It also explores gait in relation to degree of prematurity and motor development as assessed with BSID-III motor scores in children born preterm with VLBW. It was hypothesized that (i) gait parameters would be significantly different between TD toddlers and VLBW preterm toddlers with moderate-to-severe gross motor delay assessed on the BSID-III, and (ii) gait parameters of preterm children would correlate with BSID-III gross motor scores.

2. Methods

2.1. Participants

102 children born preterm (≤32 weeks GA) with VLBW were recruited in infancy from Lucile Packard Children's Hospital at Stanford in 2010 and 2011. Infants with evidence of genetic disorders or congenital brain abnormalities were excluded. Children received follow-up neurodevelopmental evaluation and gait assessment at 18–22 months adjusted age, and parentally-reported age of independent walking was recorded. 42 TD children aged 18–22 months who were born full-term were recruited from the community and Ravenswood Family Health Center in East Palo Alto. TD children were excluded if their parents expressed concerns about their gait, or if onset of walking occurred after 14 months, as in Sutherland's development of mature walking study [29]. Analysis of neonatal risk factors and neuroimaging in relation to BSID-III, gait velocity and SLS in the same cohort was previously published (Rose 2015, http://dx.doi.org/10.1038/pr.2015.157; Rose 2016, http://dx.doi.org/10.1055/s-0035-1557106). Consent was obtained from at least one parent or legal guardian of each child for this IRB-approved study.

2.2. Motor and gait assessments

A trained examiner assessed the motor development of VLBW preterm toddlers with the BSID-III at 18–22 months of age, adjusted for prematurity (adjusted age).

Gait temporal-spatial parameters of children were also calculated at 18–22 months, using a GAITRite pressure-sensitive mat (CIR Systems, Inc., Sparta, NJ). Each walking trial analyzed i) contained at least four consecutive footfalls, ii) at least one foot on the ground at any given time, and iii) the child did not touch or carry anything. If a child was not walking independently at follow-up, this was noted and the child's data was included if they were able to walk with handheld-assist. For each child, 2–3 "best effort" trials with a total of at least 12 footfalls were analyzed, selected based on walk length, straightness, and pace consistency. Velocity, cycle time, SLS, DLS, and step length, width, and time were calculated with GAITRite software. Step length and time asymmetry were calculated by normalizing the absolute difference between right and left sides by the average of right and left.

2.3. Statistical analyses

Temporal-spatial gait parameters were visually inspected for normal distribution. Means of normally-distributed gait parameters were compared using independent *t*-test (two groups) or one-way ANOVA (three groups); means of non-normally-distributed gait parameters were compared using Mann-Whitney (two groups) or Kruskal-Wallis (three groups) tests. Levene's test for equality of variances was used to select the appropriate independent *t*-test.