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Infant intralimb coordination and torque production: Influence of prematurity

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ABSTRACT

The purpose of this study is to investigate changes in leg joint coordination, intersegmental dynamics, and their relation in infants born preterm (PT) during the first months of life. Kicking actions were analyzed of 11 infants born PT at 6 and 15-weeks corrected age (CA) using three-dimensional kinematics and kinetics; results were compared to the kicking actions of 10 infants born full-term (FT). Both groups changed from a predominately in-phase coordination at 6-weeks CA to a less in-phase coordination at 15-weeks CA, however, at 6-weeks CA, infants born PT demonstrated less in-phase coordination of their ankle joints with their hip and knee joints. Between groups and across ages, both groups demonstrated consistent net and partitioned joint torque profiles, however, at 6-weeks CA infants born PT demonstrated more complex patterns of torque components. In both groups, less in-phase hip-knee coordination was associated with reduced active knee muscle torque and increased passive knee torques, however, passive knee torques had a greater influence on the kicks of infants born PT at 6-weeks CA. At 6-weeks CA, infants born PT, compared to FT, generated kicks with less in-phase hip-knee coordination, hip excursion, hip angular velocity, and hip muscle torque impulse. By 15-weeks CA, differences resolved in all variables except hip muscle torque impulse. These results highlight a different trajectory of leg joint coordination and torque production for infants born PT compared to FT.

1. Introduction

In the United States each year, approximately 450,000 infants are born preterm (Martin, Hamilton, & Osterman, 2014). Infants born preterm (PT) are at high risk for motor impairments which persist throughout childhood (de Kieviet, Piek, Aarnoudse-Moens, & Oosterlaan, 2009). The prevalence of mild-moderate motor impairment in school-aged children born PT is estimated at 40.5% (Williams, Lee, & Anderson, 2010). Due to the high rate of motor impairment in children born PT and the potential for remediation with early intervention, it is critical to develop an understanding of the differences in motor control between infants born PT and full-term (FT) to inform early identification and early intervention strategies.

The earliest coordinated movement of the lower extremities is kicking (Thelen, 1985). Infants kick spontaneously in the womb and throughout the first months of life. Infant spontaneous kicks are considered to be an important precursor to walking since they

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share similar spatiotemporal parameters with walking (Thelen, Bradshaw, & Ward, 1981) and kicking parameters have been associated with walking attainment (Jeng, Chen, Tsou, Chen, & Luo, 2004). Two aspects of kicking that require more in-depth investigation in infants born PT are joint coordination and force generation. Joint coordination has been studied (Fetters, Chen, Jonsdottir, & Tronick, 2004; Fetters, Sapir, Chen, Kubo, & Tronick, 2010; Jeng, Chen, & Yau, 2002; Vaal, van Soest, Hopkins, Sie, & van der Knapp, 2000), but force generation has not.

The joint coordination of the kicks of infants born PT and FT at term-equivalent (Heriza, 1988) and at 1-month corrected age (CA) (Fetters et al., 2004) are characterized by in-phase, synchronous flexion and extension of the hip, knee and ankle joints. By 5-months CA, infants born FT and PT generate less in-phase joint coordination during spontaneous kicking with, for example, the hip joint moving into extension as the knee joint moves into flexion, however, infants born PT demonstrate significantly less in-phase coordination among the hip, knee and ankle joints into flexion and extension (Fetters et al., 2010). The full three-dimensional (3D) analysis of joint motion is not in the literature, thus, it is unknown whether the coordination among joint angle pairs that include the rotational aspects of infant leg motion, such as hip abduction/adduction, hip external/internal rotation, and ankle eversion/inversion, are also less in-phase in infants born PT compared to FT. These rotational movements may provide a critical means of quantifying differences in leg coordination between infants born FT and infants born PT at high risk for motor impairments.

The force generated during kicking may also differ between infants born FT and PT. Fetters et al., 2010, found that at 5-months CA infants born FT compared to PT move with higher velocities and from a more extended position at the start of the movement (Fetters et al., 2010). This may indicate that infants born FT compared to PT generate more force during spontaneous kicking, although the methods used in the study precluded an estimate of force generation.

Infants born PT may also manage the forces associated with kicking differently than infants born FT. Infants kick in an environment that imposes two specific passive torques on the moving limb: a gravitational (GRA) torque related to gravity acting downward on the limb and a motion-dependent (MDT) torque related to the mechanical interactions among the moving interconnected segments of the limb. Even if infants born PT demonstrate similar force-generating capabilities as infants born FT, they may demonstrate different intersegmental dynamics, in other words, they may demonstrate differences in the anticipation and control for the effects of GRA and MDT torques that are generated as a result of their active muscle (MUS) force generation (Bernstein, 1967; Jensen, Schneider, Ulrich, & Zernicke, 1994; Sargent, Scholz, Reimann, Kubo, & Fetters, 2015; Schneider, Zernicke, Ulrich, Jensen, & Thelen, 1990). Force-generating capacity and management of intersegmental dynamics may be critical factors to understand early differences in muscle strength and motor control between infants born FT and infants born PT at high risk for motor impairments.

The purpose of this study is to investigate changes in leg joint coordination, intersegmental dynamics, and their relation in infants born PT between 6 and 15-weeks CA, as compared to infants born FT from a previous study (Sargent et al., 2015). First, we investigate changes in joint coordination between all joint angle pairs from 6 to 15-weeks CA in infants born PT. We hypothesize that, similar to infants born FT, the majority of joint angle pairs will change from a predominately in-phase coordination pattern at 6-weeks CA to a less in-phase pattern at 15-weeks CA. However, due to the additional exposure to gravity in the extra-uterine environment, at both 6 and 15-weeks CA, infants born PT, compared to FT, will exhibit less in-phase coordination between joint pairs. The second objective is to identify changes in the intersegmental dynamics of kicks from 6 to 15-weeks CA in infants born PT. We hypothesize that between 6 and 15-weeks CA infants born PT will demonstrate similar intersegmental dynamics as infants born FT; normalized NET and partitioned joint torques will remain consistent from 6 to 15-weeks CA. The third objective is to describe the relation between changes in coordination and changes in intersegmental dynamics through the analysis of the hip and knee joints into flexion and extension. We hypothesize that infants born PT will increase hip MUS torque and, similar to infants born FT, less in-phase hip-knee joint coordination will be associated with a decreased influence of knee MUS torque which allow passive knee GRA and MDT torques to have a greater influence on the coordination of the kick.

This study is a unique contribution to the literature since it is the first time that a full 3D kinematic and kinetic approach has been used to investigate joint coordination and intersegmental dynamics in a population of infants with known differences in joint coordination and potential differences in force generation.

2. Method

2.1. Participants

Infants were recruited from the Los Angeles County + University of Southern California Medical Center and by word of mouth. Eleven infants born PT ($<$ 37 weeks gestational age) and with low birth weight ($<$ 2500 g) participated in this longitudinal study at both 6 and 15-weeks CA ($\pm$ 1 week). This is the developmental period during which the transition to less in-phase coordination occurs and infants kick spontaneously in supine without attempts to roll over or grab their feet. Infants were excluded from the study based on parent report if they were diagnosed with congenital malformations, chromosomal abnormalities, prenatal drug exposure and orthopedic impairments. At 18 to 24-months CA, parents provided information on the age that the child began walking and any diagnosed medical conditions (e.g., developmental delay, cerebral palsy).

Parents signed a consent form prior to participation in the study, and families received a small gift for their participation. The Institutional Review Board at the University of Southern California approved the study. Previously published data from 10 infants born FT were used to compare differences between infants born PT and FT (Sargent et al., 2015).