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Changes in muscle activation patterns in response to enhanced sensory input during treadmill stepping in infants born with myelomeningocele

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ABSTRACT

Infants with myelomeningocele (MMC) increase step frequency in response to modifications to the treadmill surface. The aim was to investigate how these modifications impacted the electromyographic (EMG) patterns. We analyzed EMG from 19 infants aged 2–10 months, with MMC at the lumbosacral level. We supported infants upright on the treadmill for12 trials, each 30 seconds long. Modifications included visual flow, unloading, weights, Velcro and lcriction. Surface electrodes recorded EMG from tibialis anterior, lateral gastrocnemius, rectus femoris and biceps femoris. We determined muscle bursts for each stride cycle and from these calculated various parameters. Results indicated that each of the five sensory conditions generated different motor patterns. Visual flow and friction which we previously reported increased step frequency impacted lateral gastrocnemius most. Weights, which significantly decreased step frequency increased burst duration and co-activity of the proximal muscles. We also observed an age effect, with all conditions increasing muscle activity in younger infants whereas in older infants visual flow and unloading stimulated most activity. In conclusion, we have demonstrated that infants with myelomeningocele at levels which impact the myotomes of major locomotor muscles find ways to respond and adapt their motor output to changes in sensory input.

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1. Introduction

The stepping response is a cyclical patterned movement with alternating interlimb co-ordination that has been observed in neonates and fetuses (Barbu-Roth et al., 2009; Dominici et al., 2011; Forssberg, 1985; Thelen, Fisher, Ridley-Johnson, & Griffin, 1982; Thelen, Ulrich, & Niles, 1987). Researchers have also demonstrated that infants will step, when manually supported upright so their feet rest on a moving treadmill surface (Teulier et al., 2009; Thelen, 1986; Thelen & Ulrich, 1991; Ulrich, Ulrich, Angulo-Kinzler, & Yun, 2001; Yang, Stephens, & Vishram, 1998). There are a range of theories underlying the occurrence of stepping responses. Forssberg proposed that steps are a manifestation of the central pattern generator (CPG) for walking, that is, a structural network of neurons in the spinal cord predisposed for producing coupled cyclical alternating contractions of the lower limb flexors and extensors with minimal input from supraspinal centers (Forssberg, 1985). An alternative concept, based on dynamical systems theory (DST), considers that stepping, at any point in development, is the product of many intrinsic and extrinsic subsystems converging to cause patterns that continually adapt but can also stabilize with sufficient repetition (Thelen & Smith, 1994; Ulrich, 2010). The fundamental difference between these two theories is that CPG theory assumes the innate existence of dedicated networks of neurons responsible for generation of a basic cyclical activation pattern for walking. By contrast, DST takes a more global approach to the neural system and stresses the necessity of sensory input to access and strengthen over time, from among a repertoire of available neural connections, synergies of neurons that fit the context and goal (Sporns & Edelman, 1993). From a therapeutic perspective, the two theories offer very different prognoses regarding development of stepping and walking, following an embryonic spinal cord lesion. In the event of a spinal cord lesion, such as myelomeningocele (MMC) impacting the primitive locomotor neurons, stepping could be lost, or display aberrant patterns according to classical CPG theory. However, DST postulates that behaviors fit the context and task, given the available resources and contexts. Repeated cycles of sensory input coupled with functional motor output drives the change in neuromotor networks producing a stepping response even in the presence of extensive spinal cord lesioning. Similarly, neuroscience research on the developmental organization of the brain and spinal cord emphasize the plasticity within the system, both in typical development and neurorehabilitation (Karmiloff-Smith, 2009; Kleim & Jones, 2008).

A factor known to affect step frequency and interlimb coordination is the infants' neural and physiological makeup, with fewer steps produced by infants with myelomeningocele (MMC) and Down syndrome (DS) compared to infants with typical development (TD) (Teulier et al., 2009; Ulrich, Ulrich, & Collier, 1992). In these infants, the feedforward and feedback loops organizing movement patterns are diminished, thus compromising the step response compared to infants with an intact nervous system. However, even in these clinical populations we have previously reported a change in the parameterization of their steps and increased step frequency in response to some forms of enhanced sensory inputs (Pantall, Teulier, Smith, Moerchen, & Ulrich, 2011; Ulrich, Ulrich, & Angulo-Kinzler, 1998). Visual flow increased treadmill step rate significantly in the older infants but not in younger infants. Specifically, enhanced sensory inputs via visual flow and friction on the treadmill belt significantly increased step rate, particularly for older (7–10 months) compared to younger (2–5 months) infants for whom only friction increased stepping (Pantall et al., 2011).

In this study we focus on the stepping response of infants with a lumbar or sacral myelomeningocele (MMC). MMC is the most common neural tube defect in the US (Bowman, Boshnjaku, & McLone, 2009), present in the spinal cords of approximately 1 in 3000 live births (Canfield et al., 2006). The relevance of studying this type of clinical population is to determine system adaptability, given that the link between the peripheral sensory and motor neurons, spinal interneurones and supraspinal components may be compromised, thereby disrupting neurophysiological and consequentially locomotor function. The clinical neurological picture presents as a combination of lesions of the lower and upper motor neurons, disturbed sensory pathways and compromise of the autonomic system at and distal to the level of the MMC. Commonly associated orthopaedic problems that may additionally impact gait include scoliosis, talipes equus, subluxated hip and muscle contractures (Iborra, Pages, & Cuxart, 1999; Norrlin, Strinnholm, Carlsson, & Dahl, 2003; Swaroop & Dias, 2009). Infants with MMC