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Original article

An fNIRS exploratory investigation of the cortical activity during gait in children with spastic diplegic cerebral palsy

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Abstract

Objective: The primary aim of this exploratory investigation was to determine if there are differences in cortical activation of children with spastic diplegic cerebral palsy (CP) and typically developing children during gait. *Methods:* Functional near-infrared spectroscopy was used to measure the concentration of oxygenated hemoglobin that was present in the supplementary motor area, pre-central gyrus, post-central gyrus and superior parietal lobule as the children walked on a treadmill. A sagittal plane video was concurrently collected and later digitized to quantify the temporal gait variations. *Results:* (1) The children with CP had an increased amount of activation in the sensorimotor cortices and superior parietal lobule during gait, (2) the children with CP had a greater amount of variability or error in their stride time intervals, and (3) an increased amount of error in the temporal gait kinematics was associated with an increased amount of activity across the cortical network. *Conclusion:* Our results suggest that the perinatal damage and subsequent neural reorganization that occurs with spastic diplegic CP may impact the functional cortical activity for controlling gait. Furthermore, our results imply the increased cortical activity of the somatosensory cortices and superior parietal cortices may underlie the greater amount of error in the temporal gait kinematics.

Keywords: Walking; Variability; Motor control; Mobile brain imaging

1. Introduction

One of the leading causes of childhood disability is cerebral palsy (CP), which often results from a perinatal brain injury. Over 90% of these children present motor impairments that result in a gait pattern that is slower, less coordinated, and has a greater amount of variability or errors in the temporal kinematics [1,2]. A considerable amount of effort has been devoted to using structural magnetic resonance imaging (MRI) and diffusion tensor imaging (DTI) to understand if damage in the respective lobules and fiber tracts is related to the atypical motor performance seen in children with CP. The general consensus is that children who have a higher Gross Motor Function Classification Score (GMFCS) tend to have more extensive damage to the corticospinal and thalamocortial pathways [3–5]. In addition, it has been further reported that the extent of the damage to the these tracts is related to lower extremity weakness and deficient gait biomechanics [5,6].

Despite the noted structural damage, numerous transcranial magnetic stimulation (TMS) investigations have shown that the sensorimotor cortices of children

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with CP often dynamically rewire themselves throughout development. For example, in children with more severe hemiplegic presentations, the ipsilateral homologue cortices often assume the role of the damaged contralateral cortices that would normally be involved in the control of movement [7,8]. Likewise, in children with less severe brain injury, it has been shown that the locale of neuronal populations that control the leg muscles are more lateral in the homunculus topology [9], which suggests cortical reorganization of neural representations of the leg.

Very few investigations have evaluated the activity of the sensorimotor cortices during movement in children with CP [10–14]. The outcomes of these functional MRI (fMRI) studies have indicated that the unaffected hemispheres in children with hemiplegic CP often assume the role of the damaged hemispheres while performing a finger-to-thumb opposition motor task [10,11,13]. In addition, it has been shown that bilateral activation of the sensorimotor cortices and the contralateral premotor cortex often occurs when children with spastic diplegic and quadraplegic presentations perform a finger-to-thumb opposition task [12]. It is unknown how these differences in neural activity affect the motor performance of children with CP since biomechanical data was not concurrently collected during these experiments. In addition, the ecological validity of these experimental outcomes is limited because they are based on simplified motor tasks. Although these experimental outcomes are enlightening, they still do not address if the neuroplastic changes normalize the activity of the sensorimotor cortices, or result in additional challenges to nervous system function that may increase the probability for errors in the motor performance.

Functional near-infrared spectroscopy (fNIRS) is an emerging neuroimaging technique that measures the hemodynamic changes that occur in cortical tissues during movement [15]. During fNIRS experiments, children wear a cap that contains a series of photon emitters and detectors, and this cap is situated on the scalp near a brain region of interest. The emitters produce infrared light that penetrates the skull and is absorbed or refracted by hemoglobin in the underlying neural tissues. The total refraction measured by the detectors is used to quantify the amount of oxygenated (oxyHb) and de-oxygenated (deoxyHb) hemoglobin in local neural tissues. It has been well established that a greater concentration of oxyHb is associated with a greater amount of activity in the underlying neural tissues [15].

fNIRS has an advantage over other imaging modalities because it is less susceptible to head movements, quiet, does not require a confined environment, and it can be used to evaluate cortical activity during ecologically valid motor tasks such as walking [16,17]. Prior fNIRS experiments have shown that the amount of cortical activity is greater during challenging walking conditions [16,17]. For example, during walking, the amount of activity across the cortical network is reduced when stroke patients are supported by an overhead support system [17]. Additionally, it has also been shown that a greater amount of cortical activity is associated with a more variability or errors in the gait temporal kinematics [16]. Based on these novel insights, we suspect that children with CP would have a greater amount of cortical activity while walking because their spatiotemporal kinematics are more variable and potentially more challenging to control [16].

In this exploratory investigation, we used fNIRS to measure the concentration of oxyHb that was present in the sensorimotor cortices as children with and without CP walked on a treadmill. We quantified the differences in the amount of activation in the cortical networks that are involved in the control of gait by monitoring the change in the concentration of oxyHb. Our primary aim was to explore if children with CP have an increased amount of neural activity across the cortical network during gait compared with typically developing (TD) children. Our secondary aims were to further probe the relationship between the amount of neural activity, and the amount of variability seen in the gait temporal kinematics of the children with CP.

2. Materials and methods

2.1. Participants

The University of Nebraska Medical Center's Institutional Review Board approved this investigation. The participating children were recruited from the physical therapy clinic at the University of Nebraska Medical Center, where they had previously received treatment or had undergone a gait analysis. Four children with spastic diplegic CP (Age = 11.0 ± 4 yrs.) and eight TD children (Age = 13.2 ± 3 yrs.) volunteered to participate in this investigation. Written informed consent was acquired from the parents and the children assented to participate in the experiment. The children with CP had a previously defined diagnosis of CP by a pediatric neurologist. For all of the children, the resulting CP was a result of periventricular leukomalacia, and they had a spastic diplegia presentation. Children with known large occupying lesions and/or volume loss that would have affected the cortical tissue were not included in our investigation. Three of the children with CP had GMFCS of II and wore orthotics during ambulation. The other child with CP was classified as GMFCS III and required forearm crutches for ambulation. The participating TD children were free of any neurologic and/or orthopedic impairment that would have affected their gait. Further descriptions of the participating children are detailed in Table 1.