INTRODUCTION

Cerebral palsy (CP) results from a perinatal brain injury that can impact the neuromuscular control of the lower extremities. A considerable amount of research efforts have been placed on cataloging and quantifying the motor impairments seen at the knee joint because it has been cited as a critical factor that limits the mobility of these children. These studies have shown that children with CP often present a wide variety of musculoskeletal impairments that may limit the knee’s performance (e.g., co-contractions, spasticity, weakness, contractures). Based on these insights, the majority of treatment approaches have used a bottom-up treatment approach (e.g., surgery, strength training) in hopes of improving the knee joint’s motor performance. However, systematic reviews indicate that there is little scientific support for these approaches, as the outcomes are often mixed and unpredictable [2]. Few investigators have suggested that the motor control problems seen in children with CP may be partially related to an abnormality in the ability of sensorimotor cortices to formulate a motor plan [1,3]. These studies have noted that children with CP have slower reaction times, and errors in muscular force production when performing motor tasks with the upper extremities. However, despite these novel behavioral insights, limited efforts have been made to evaluate if these results are due to aberrant activity of the sensorimotor cortices during the motor planning stage. Furthermore, no studies have evaluated if similar motor planning deficits exist while children with CP attempt to control the lower extremities; including the knee joint.

Magnetoecephalography (MEG) is the only brain imaging technique that can accurately separate the motor planning and execution stages of the sensorimotor cortices. Previous MEG studies have established that the beta-frequency (15-30 Hz) oscillatory activity in the sensorimotor cortices decreases before the movement onset, and represents the motor planning stage [4]. Moreover, it is well known that gamma-band (>50 Hz) oscillatory activity in the primary motor cortex is related to the execution of the motor command [4]. While the central role of beta and gamma neural oscillatory activity during movement is well appreciated, there has been no effort to use this knowledge to more precisely characterize the motor deficits seen in children with CP.

The purpose of this investigation was 1) to determine if motor planning deficits are present in children with CP while performing an isometric knee joint task, 2) to determine if beta event related desynchronization (ERD) and gamma event related synchronization (ERS) is altered in children with CP while moving the knee joint, and 3) to determine if there is a relationship between the beta ERD and gamma ERS and muscular control of the knee joint.

METHODS

Thirteen children with spastic diplegic or hemiplegic CP (Age = 11 ± 4 yrs.) and thirteen typically developing (TD) children (Age = 13.2 ± 3 yrs.) participated in this investigation. An isokinetic dynamometer (Biodex Inc., Shirley, NY) was used to measure the steady-state isometric torques generated by the knee joint extensors. The motor task involved matching and holding a target torque that was 20% of the child’s maximum voluntary
torque for 15 seconds. The target and the torque exerted by the child were displayed on a large monitor positioned ~1 meter away. The time to reach the target force was used as a surrogate assessment of the certainty of the motor plan. Additionally, the coefficient of variation (CV) was used to assess the steadiness of the motor output after the target value was achieved. A greater amount of variability was assumed to indicate more errors in execution and adjustment of the motor plan to remain at the target value.

A whole head 306-sensor MEG system (Elekta Neuromag, Helsinki, Finland) was used to assess the oscillatory activity of the sensorimotor cortices as children extended their knee when cued by an auditory stimulus. A linearly-constrained minimum variance vector beamformer algorithm was used to calculate 3D images that reflect the local power of neuronal current [4]. The single images generated were derived from the cross spectral densities of all combinations of MEG sensors averaged over the time-frequency ranges of interest. The beamforming analysis was performed for the beta-frequency spectrum (14-28 Hz) preceding movement onset, and the high-frequency gamma spectrum (>40 Hz) slightly preceding and during movement execution.

RESULTS AND DISCUSSION

The biomechanical results indicated that the children with CP took longer to reach the target (CP = 2.78 ± 0.20 sec; TD = 1.62 ± 0.13 sec; p < 0.05), and had greater errors in their ability to sustain the steady-state torque values (CP = 8.26 ± 2.30%; TD = 3.27 ± 0.48%; p < 0.05). These results imply that the children with CP take longer to formulate a motor plan, and have greater errors in adjusting and/or sustaining the motor output to match the desired motor output.

Exemplary results for a TD child and a child with CP are shown in Figure 1. The group MEG results indicated that children with CP had greater beta ERD responses (CP = -25.48 nAm; TD = -4.47 nAm; p < 0.05), and lower gamma ERS (CP = -16.93 nAm; TD = 6.82 nAm; p < 0.05) than the TD children. These results are the first to show that there is abnormal activity in sensorimotor cortices during the motor planning stage, which may impact the later execution of the motor command by the primary motor cortices.

There was a moderate (r = -0.48; p<0.05) negative correlation between gamma ERS and the time taken to reach the target. Indicating that children who took longer to reach the target had a lower gamma ERS in the sensorimotor cortices. There also was a moderate (r = -0.48; p<0.05) negative correlation between the beta ERD and the CV. Indicating that greater errors in the knee joint’s steady-state muscular performance were related to greater beta ERD during the motor planning stage.

Our results support the notion that children with CP have deficits in the formulation and execution of the motor command. We suspect that interventions focused on improving the ability of children with CP to formulate an adequate motor plan may result in an improved ability to control the knee joint.

REFERENCES