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Reliability of the Location of Primary Motor Cortex Using the International 10/20 Electroencephalogram System (10/20 EEG)

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In stroke recovery, the activation of the primary motor cortex (M1) is critical for motor learning and has been found to be augmented by non-invasive brain stimulation (NIBS) recovery [1,2]. One form of interventional NIBS is transcranial direct current stimulation (tDCS), which involves the guided placement of electrodes on the scalp. Two methods to guide the somatotopic localization of the M1 area are 1) transcranial magnetic stimulation (TMS) and 2) the 10/20 International Electroencephalogram Coordinate System (10/20 EEG) [3]. The TMS M1 location, termed the motor hotspot, is derived by eliciting a motor evoked potential in a muscle corresponding to the area stimulated (e.g. the first dorsal interosseous muscle can be monitored when stimulating the hand knob of M1). In contrast, the 10/20 EEG identifies the location of M1 for the placement of scalp electrodes derived from four key individual anatomical landmarks with the nasion (lowest depression between the forehead and nose), in (lowest point of the skull from the back of the head) and the preauricular points of the right and left ears. EEG electrodes can record temporal brain activity in the form of event-related potentials (ERPs). The ERP represents a summation of neuronal activity and the location of the brain activity is inferred based on the type of task or stimuli (e.g. a motor task may infer activity in the M1 area). The coordinates for M1 include C3 (left hemisphere) and C4 (right hemisphere) areas regardless the possible cortical re-organization of M1 following a stroke.

Although the 10/20 EEG was originally designed to record brain activity, increasing investigations of tDCS in adults and children with stroke are reporting use of the 10/20 EEG to guide tDCS electrode placement. However, the reliability of the 10/20 EEG measurements to locate the C3 and C4 is unknown. The purpose of this study was to assess the inter-rater and intra-rater reliability of the 10/20 EEG to localize C3 and C4 to provide information about the error of this measure when used by a researcher with limited training in EEG measurements. These results may inform other investigators who design non-invasive brain stimulation research protocols where stimulation location is determined by the 10/20 EEG measurements. This research was approved by the Institutional Review Board at the University of Minnesota. A convenience sample of twenty-five adults without neurological conditions were recruited (mean age = 42.04, SD = 13.67). All participants provided written consent.

Two investigators unfamiliar with performing 10/20 EEG measurements were provided with two hours of training with a pediatric neurodiagnostic technician. Following training, independent measurements of participant's heads were completed following the 10/20 EEG [4]. The C3 and C4 areas were localized and the distances between 1) left preau-

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ricular notch to C3 and 2) right preauricular notch to C4 were measured. For inter-rater reliability, two raters measured the same 25 participants at different times within the same day. For intra-rater reliability, only one rater evaluated the same 25 participants in two different, consecutive days.

The relative reliability was determined using the ICC and the absolute reliability was determined by calculating the SEM (SEM = $\sqrt{WMS}$, where WMS is the within-subject mean square error term from 1-way analysis of variance). The ICC values were considered poor when below 0.20, fair from 0.21 to 0.40, moderate from 0.41 to 0.60, good from 0.61 to 0.80, and very good from 0.81 to 1.00 [5]. The ICC analyses were performed using SPSS Version 17 (SPSS Inc, Chicago, IL) and the SEM was calculated using the Excel 2007. The ICC for the inter-rater reliability of the distance between left preauricular notch to C3 was 0.36 (95% confidence interval = -0.03-0.65) and the SEM was 0.50. The ICC for the inter-rater reliability of the distance between right preauricular notch to C4 was 0.05 (95% confidence interval = -0.34-0.43) and the SEM was 0.58. The ICC for the intra-rater reliability of the distance between left preauricular notch to C3 was 0.36 (95% confidence interval: -0.4-0.66) and the SEM was 0.34 cm. The ICC for the intra-rater reliability of the distance between right preauricular notch to C4 was 0.60 (95% confidence interval: -0.27-0.80) and the SEM was 0.34 cm.

This study evaluated the inter and intra-rater reliability of C3 and C4 locations using the 10/20 EEG. The study showed a low to fair inter and intra-rater ICC for the distance between left preauricular notch to C3 and between right preauricular notches to C4. The ICC depends in part on the between-subjects variability of the measurement, therefore the low to fair inter and intra-rater ICC could be attributed to low variability in the head size of these study participants. The low SEM indicates a small amount of absolute error of the measurement within and between raters. Our results suggest that the use of the 10/20 EEG may result in a low error (less than 1 cm) when localizing C3 and C4 by different novice raters and in different days.

The study was limited by procedural measurement standardization and a lack of three-dimensional analysis of disparities in our inter-rater and intra-rater measurement. The tension of the tape measure and hair management during all measurements was not standardized. Additionally, a clinical non-toxic marking pen (China™ pencil), which has a larger tip was used for this study to mark head-specific measurements. These together could have contributed to the errors in the measure. The addition of three-dimensional measurements in a future study would provide information as to the directionality of the displacement error (e.g. anterior, posterior, superior, inferior) of C3 and C4 location observed inter and intra-raters. Despite these limitations, our study indicates that the 10/20 EEG can result in low SEM, when localizing C3 and C4, by different novice raters and on different days. Although limitations exist within this study design, there are limited reports of the reliability of the 10/20 EEG when used by different investigators and on different days.

The 10/20 EEG frequently guides electrode placement for tDCS although few studies report reliability of 10/20 EEG measurements. A lack of reporting reliability in 10/20 EEG measurements may be contributing to greater inter-individual variability following tDCS intervention. In addition, the 10/20 EEG does not take into consideration the influence of continued development of children following stroke when localizing the M1 area. The influence of development on reorganization of the motor cortex after stroke could limit the accuracy of the 10/20 EEG to locate the M1. As we consider not only reliability but also validity, other's data suggests poor validity of the 10/20 EEG measurements to localize the motor cortex in adults without neurological condition [6,7]. Future studies incorporating neuroimaging may elucidate the validity of the use of 10/20 EEG to locate the M1 in children with stroke who may display reorganization of M1.

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