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# Inter-joint coordination analysis of reach-to-grasp kinematics in children and adolescents with obstetrical brachial plexus palsy

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ABSTRACT

*Background:* Obstetrical brachial plexus palsy is a common birth injury to nerves passing through the brachial plexus that may result in structural and functional abnormalities. Individual joint trajectories from kinematic analyses have been used to evaluate the source and extent of abnormalities. Here, two summary measures of limb kinematics were utilized: 1) the Arm Profile Score summarizing upper limb joint kinematic abnormalities from a typical pattern across a task, and 2) the recently developed Multi-joint Coordination Measure using principal component analysis to characterize typical coordination of multiple joints throughout a task and compute deviations in time and space. Our aim was to compare these kinematic measures in persons with and without injury and relate these to clinical and functional scales.

*Methods:* 3D kinematic data from 10 upper limb joints were collected on 15 children and adolescents with obstetrical brachial plexus palsy and 21 controls during a reach-to-grasp task in both limbs. The two kinematic measures were computed and correlated with each other and the Mallet and ABILIHAND-Kids.

*Findings:* Both measures revealed that joint angles primarily contributing to shoulder and wrist motion were most prominently affected in the non-dominant limb in obstetrical brachial plexus palsy, with the Multi-joint Coordination Measure additionally indicating when in the motion coordination worsens. These were moderately interrelated but neither correlated with other scales.

*Interpretation:* The Multi-joint Coordination Measure, while related to the Arm Profile Score, may have additional utility for individualized treatment planning and evaluation of any motor task due to the unique spatial-temporal information provided.

## 1. Introduction

Obstetrical brachial plexus palsy (OBPP) is a peripheral nerve injury that occurs in approximately 1 to 4 of 1000 live births (Chauhan et al., 2014; Hoeksma et al., 2004) and is coincident to complications in utero or childbirth, e.g., macrosomia, shoulder dystocia, prolonged labor, and complicated deliveries (Dodds and Wolfe, 2000). OBPP may be sub-classified according to injury level; e.g., Erb's palsy affecting C5-C6, extended Erb's palsy affecting C5-C7, Klumpke's palsy affecting C8-T1, and complete palsy affecting C5-T1, where each level innervates different muscle groups of the upper limbs and has different afferent input. While many infants with OBPP have transient injuries, at least 20% sustain permanent injuries leading to movement limitations and strength imbalances of the affected limb (Brochard et al., 2014) that may hinder activities of daily living such as grooming, dressing, feeding and other tasks (Dodds and Wolfe, 2000). Persistent neurological deficits may lead to secondary musculoskeletal impairments, such as scapular dysplasia, abnormal glenohumeral morphology, and eventual posterior shoulder dislocation, which further restrict upper limb coordination and function (Dodds and Wolfe, 2000; Pearl and Edgerton, 1998; Price et al., 2000; van Gelein Vitringa et al., 2013; Waters et al., 1998; Waters et al., 2009). Motor habilitation therapies are often prescribed in OBPP. However, determining the most effective interventions is often challenging due to variable recovery patterns that produce multi-joint and multi-planar impairments that disrupt functional movements in different ways across individuals.

Current clinical scales developed to systematically evaluate children with OBPP are useful in identifying the basic patterns and extent of

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involvement but provide limited information on specific joint kinematic contributions to a given movement. Measures such as the Narakas classification (Narakas, 1987) and Mallet score (Mallet, 1972), have been developed and validated mainly to evaluate passive and active range of motion of the impaired limb. As suggested by Mosqueda et al. (2004), 3-dimensional kinematic analysis enables clinicians to measure multi-planar functional limitations in the upper limbs and may provide valuable information for pre- and post-clinical evaluations in OBPP. Accordingly, previous kinematic studies of children with OBPP have evaluated individual joint trajectories, demonstrated a loss of active shoulder motion in the impaired limb (Mosqueda et al., 2004) due to abnormal scapulothoracic (ST) and glenohumeral (GH) joint contributions during movement when compared to their unimpaired dominant limb (Duff et al., 2007) or either limb in typically developing children (Russo et al., 2014). In addition, children with OBPP have shown increased variability in arm movements and inter-limb differences in arm resting position, which may relate to observed compensatory strategies (Duff et al., 2007; Mosqueda et al., 2004; Russo et al., 2014). However, these analyses focused on single joint trajectories rather than focusing on the coordination of multiple joint angles. Since activities of daily living depend on concurrent movement of many joints, novel kinematic methods that take into account multiple joint angles in their analysis may have greater clinical utility.

The Arm Profile Score (APS) (Jaspers et al., 2011) was developed to summarize multiple upper limb joint kinematic abnormalities averaged over the duration of the task of interest. While this measures the extent of involvement in individuals at a single point in time or before and after intervention, the APS does not provide information on when during the task that movement patterns deviate from a typical kinematic pattern. Recently, the Multi-joint Coordination Measure (MJCM) (Kukke et al., 2015) described by Kukke et al. was created to quantify abnormalities in time-varying multi-joint coordination patterns at each 1% of task duration. Additionally, it provides a visual as well as a quantitative depiction of which joints deviate the most from the typical pattern during different phases of the task for a single individual or averaged across a group, while providing a summary score of kinematic abnormalities across joints and time similar to the APS.

Our objective was to quantify multi-joint upper limb kinematics during a functional reach task in children and adolescents with unilateral OBPP at an individual and group level when compared to the uninvolved limb and to a group of participants within the same age range with no upper limb involvement. The reach task was selected because of its importance for performing activities of daily living (Butler et al., 2010). Both the APS and the MJCM, initially used in individuals with child onset brain injuries, were utilized and compared for the first time in this population, and their summary scores were related to other clinical and functional scales in OBPP. We hypothesized that individuals with OBPP would have significantly greater joint kinematic abnormalities as indicated by both the APS and the MJCM in the impaired limb compared to their contralateral limb and to both limbs in typically developing children and adolescents (TDCA). Moreover, because the same kinematic data were applied to the APS and MJCM, we hypothesized that these would be moderately or highly correlated. We also expected that the APS and MJCM would be related to the clinical and functional scales used in our study, based on the strong positive relationships found between the MJCM and functional scales in earlier work from our laboratory on individuals with child-onset brain injuries. Lastly, in terms of treatment planning or outcome assessment for an individual patient with a complex multi-joint injury, we hoped to demonstrate the greater utility of the MJCM since it provides detailed quantitative information across task time and joint space that is not available with the APS.

## 2. Methods

### 2.1. Participants

Fifteen children and adolescents with unilateral OBPP (10 male, 5 female) with a mean age of 11.5 years (SD 3.5) completed comprehensive evaluations of muscle and joint integrity and function. Inclusion criteria were: age 5–18 years inclusive, unilateral OBPP from birth, and ability to flex and abduct the impaired arm at least 30°. Exclusions were any other significant neurological or orthopedic impairment, surgery in the past year, botulinum toxin injections to upper limbs within 6 months, inability to follow verbal directions or too small to fit reliably and comfortably in the standardized testing set-up. A comparison group of 21 TDCA (10 male, 11 female) with a mean age of 11.8 (SD 2.7) with no history of musculoskeletal or neurological problems also participated. Written informed consent was obtained from parents of children under 18 years. Children 7 years or older also provided written assent. One participant who was 18 years old provided written consent. The protocol was approved by the institutional review board at the National Institutes of Health, Bethesda, MD.

### 2.2. Procedures

Medical histories were reviewed to confirm eligibility. A pediatric physiatrist performed a physical examination of joint passive range of motion in both upper limbs. The Mallet Scale and ABILHAND-Kids measure were conducted on the impaired (non-dominant) limb in OBPP to assess shoulder function and manual ability of the non-dominant limb, respectively.

The Mallet scoring system (Mallet, 1972) assesses shoulder abduction/external rotation limitations by evaluating active range of motion in shoulder abduction and external rotation, for tasks such as hand to top of head, hand to mouth, and back of hand to lower spine. Performance for each of the 5 motions was assigned a score from 1 (no motion) to 5 (normal range of motion), with a maximum total of 25. Lower scores (5) indicate more limited range of motion.

The ABILHAND-Kids (Arnould et al., 2004), a global measure of manual ability, was utilized to assess the level of disability and to relate kinematic impairments to functional limitations. It is a questionnaire, comprised of 21 manual activities. The parents of individuals with OBPP were ask to report perceptions of their child's ability to perform the tasks on a 3-level rating scale: impossible (0), difficult (1), or easy (2). The participant aged 18 years reported perceptions of their own ability. Raw scores were used with higher scores (maximum = 44) indicating greater function, but these can also be converted to logits using a Rasch analysis.

For the reach-to-grasp, all participants were seated comfortably in an armless chair with their feet on the ground with ankle in neutral and the hips and knees flexed 90°. A cylindrical rod (6 in. height × 2 in. diameter) was placed on a table at elbow height and at a distance near but less than maximum reach for each individual. A reflective marker was placed on top of the rod to track its location. Joint coordinate system definitions and the placement of thirty-four reflective markers on the upper limbs and trunk were based on ISB-recommendations (Wu et al., 2005) with the exclusion of a clavicle marker. Additionally, we included a 4-marker cluster on the humerus for upper arm tracking, a 3-marker cluster on the acromion for scapular tracking, markers on the ulna distal to the olecranon and on the styloids for forearm tracking, and used functional calibration (Schwartz and Rozumalski, 2005) to estimate the shoulder joint center.

Three-dimensional motion of the markers was captured using a 10-camera, Vicon MX system (Vicon Motion Systems, Oxford, UK) at a rate of 100 Hz. The reach task began with the arm hanging freely at the participant's side with the contralateral hand resting on the lap. After being instructed to begin, the subject reached towards the rod at a self-selected pace with the suspended hand, and the task ended when the