2019 16th International Conference on Electrical Engineering, Computing Science and Automatic Control (CCE) Mexico City, Mexico. September 11-13, 2019

Muscular Activation during Low Resistance Elbow's Motion of Children with and without Cerebral Palsy

Alberto Isaac Perez Sanpablo
Department of Automatic Control and Laboratory of Human Motion Analysis
CINVESTAV and National Institute of Rehabilitation "Luis Guillermo Ibarra Ibarra"
Mexico City, Mexico
alberto.perez@cinvestav.mx

Catherine Disselhorst-Klug
Department of Rehabilitation and Prevention Engineering
RWTH Aachen University
Aachen, Germany
disselhorst-klug@ame.rwth-aachen.de

Alicia Meneses Peñaloza
Department of Pediatric Rehabilitation
National Institute of Rehabilitation "Luis Guillermo Ibarra Ibarra"
Mexico City, Mexico
ameneses@inr.gob.mx

Elisa Romero Avila
Department of Rehabilitation and Prevention Engineering
RWTH Aachen University
Aachen, Germany
romero@ame.rwth-aachen.de

Juan Manuel Ibarra Zannatha
Department of Automatic Control
CINVESTAV
Mexico City, Mexico
jibarra@cinvestav.mx

Josefina Gutierrez Martinez
Department of Medical Engineering
National Institute of Rehabilitation "Luis Guillermo Ibarra Ibarra"
Mexico City, Mexico
jgutierrez@inr.gob.mx

Maria Elena Arellano Saldaña
Department of Pediatric Rehabilitation
National Institute of Rehabilitation "Luis Guillermo Ibarra Ibarra"
Mexico City, Mexico
marellano@inr.gob.mx

***Abstract*—Here we analyze the effects of load, contraction type, joint position and joint angular velocity on coordination of elbow's muscle activity during low resistance motion of children with and without cerebral palsy (CP) by joint position and velocity non-linear categorization of surface electromyographic (sEMG) activity. Seven healthy children and four children with CP from 6 to 13 years old were assessed. Main and mixed effects for all conditions on sEMG activity were analyzed by ANOVA tests. Linear regressions for sEMG and joint angle velocity were calculated and the effects of group, load and muscle on the slope of linear regressions were analyzed by ANOVA tests. Observed muscular coordination for all test conditions ($p<0.01$, mean power of 80%) agreed with previously reported muscular coordination of adults. Increased sEMG activity for CP children and high angular velocity were found. Children with CP showed differences ($p<0.01$) on linear regression slopes (mean RMSE= 0.07 and mean $R2=0.06$) during fine-tuning control tasks for biceps and triceps medialis. In this study we found evidence based on a time domain analysis of muscular activity which helps to confirm the presence of a common muscle coordination mechanism previously suggested to be present in healthy children. Also, we found novel evidence to support the idea that this control is altered in children with neuromuscular conditions such as CP. This information may be useful for diagnosis and treatment of neuromusculoskeletal conditions in children.**

Keywords— surface electromyography, sEMG, elbow joint, children, cerebral palsy

I. Introduction

Motion of the upper limb is fundamental for the performance of activities of daily living. Elbow joint plays a major role for upper limb's motion. Study of elbow joint using surface electromyography (sEMG) has been proposed as a way to obtain non-invasively insights of human motor control which can be used for the diagnosis and treatment of neuromusculoskeletal conditions[1][2], and for the design of rehabilitation and assistive technology[3]. Variations of load, joint position and angular velocity across major muscles involved in elbow joint motion have been studied. Previously, Von Werder observed in healthy adults a coordinated muscular activation of biceps and brachioradialis during load bearing tasks and an oposite muscular activation during fine-tuning control tasks[4]. Similarly, Kholine described differences in muscular activation of different heads of triceps brachii during elbow movements at different shoulder elevations[5]. Also, an uncoupling of agonistic and antagonistic muscles in order to attain high speeds movements was observed in healthy children[6]. However, Neuromusculoeskeletal conditions can alter upper limb's motion. For example, cerebral palsy (CP) which is the most common condition in children[7] affects approximately 12,000 new children in Mexico each year [8]. Children with CP showed muscle weakness, involuntary muscle coactivation, loss of muscle control, joint stiffness, muscle atrophy, contractures, which in turn can cause osteoarticular deformities, pain and compensatory mechanisms [9][10]. As a result consideration of variations on load, joint position, joint angular velocity across muscles of elbow joint are necessary in order to attain better estimates of elbow joint dynamics [11] and to describe muscular coordination in this population. Therefore, the objective of this work is to describe muscular activation during low resistance elbow's motion of children with and without CP.

II. Material and Methods

In order to analyse muscular activity during flexion and extension movements of the elbow joint, surface

Research sponsored by the National Council of Science and Technology (CONACyT), project FONCICYT 26773

978-1-7281-4840-3/19/$31.00 ©2019 IEEE

electromyography (sEMG) of brachioradialis (BRD), biceps brachii (Bic), triceps lateralis (Tlat) and triceps medialis (Tmed) was measured in children with and without CP older than 6 years old. Inclusion criteria for children with CP were presence of hemiplegia or diplegia and a modified Ashworth score between 1 and 2. Children performed active flexion and extension movements of elbow joint from 0° to 135° at four angular velocities against two load resistances. SENIAM recommendations[12] about electrode positioning were followed. Electrodes were connected to four SX230FW preamplifiers and a datalogger (Biometrics ltd, UK) working at a sampling frequency of 1000Hz.

In order to keep control of motion kinematics and motion resistance during flexion and extension movements a pulley machine (Mobile Speed Pulley, Lojer, Finland) and the biofeedback Koakin-motion software (RWTH University, Germany) were used[13], see Fig. 1. To impose a constant resistance along full range of elbow's motion, children's arm was attached to the pulley machine by a lever with a radius of 4cm. Four pulley configurations were used: 1)0.5kg load flexion resistance, 2)1kg load flexion resistance, 3)0.5kg load extension resistance, 4)1kg load extension resistance. Motion was repeated twice with one-minute rest period between repetitions in order to avoid subjects' fatigue. Subjects were asked to match a preset sinusoidal trajectory displayed on a monitor in front of them by performing flexion and extension elbow's movements while attached to the pulley machine by using Koakin motion software. Sinusoidal trajectory consisted of sinusoidal flexion-extension segments at four velocities (30°/s, 50°/s, 80°/s, 100°/s) on a random order. Each trial contains two repetitions for each velocity. An electrogoniometer SG110 (Biometrics ltd, UK) was attached to subject's arm to register elbow's position.

Institutional research and ethics committees approved the measuring protocol. All subjects and parents gave their informed assent and consent respectively prior to any acquisition of data.

Figure 1. Setup of elbow's kinematics and muscular activity acquisition. Attachment of subject's arm to Pulley machine (Lojer, Finland) wearing four SX230FW preamplifiers and one SG110 electrogoniometer (Biometrics ltd, UK).

Muscular activity and elbow's position were processed using same methods as previously reported [4][6] to allow further comparison of results. Elbow's angle was filtered using a low-pass 4th order Butterworth filter with a cutoff frequency of 6.6 Hz to remove noise and artifacts. Gradient of elbow's position was calculated to obtain elbow's velocity. Envelopes of sEMG were obtained by filtering sEMG raw data using a zero lag 18th order Butterworth filtered with a passband from 10 to 450 Hz, after which signals were rectified and smoothed using a moving average filter with a window size of 80 ms. Envelopes of sEMG were normalized with respect to each subject's maximum obtained along all resistance configurations.

Muscular activity was categorized, on a similar way to previous studies [13], according to muscle (Bic, Tmed, BRD, Tlat), group (children with and without CP), type of contraction (flexion and extension) and external resistance (0.5 kg or 1 kg) in 4 joint angle, and 4 joint angular velocity categories to make sEMG envelopes comparable to identify at least a difference of 5% with a statistical power of 80%. In total, 128 categories of sEMG envelope per muscle were assessed (two groups x two types of contraction x four joint angular velocity intervals x four joint position intervals x two resistances).

One three-way ANOVA test ($p<0.05$) was conducted on the normalized sEMG envelope to determine the effects of 1)group, 2)load and 3)contraction type for each muscle. To evaluate the effects of 1)group, 2)joint angular position and 3)joint angular velocity for each muscle at each resistance and type of contraction, a second three-way ANOVA test was conducted on the normalized sEMG envelope using a significance level $p<0.05$. Normalized sEMG envelope data were transformed to a normal distribution to fulfil requirements of ANOVA tests. Linear regressions of normalized sEMG envelope and velocity were created to compare the effect of velocity for different muscles. ANOVA tests ($p<0.05$) were conducted on the slope of linear regressions to determine main and mixed effects of 1)group, 2)load and 3) muscle. Whenever it was needed a transformation to a gaussian distribution for the slope of linear regressions was used.

III. Results

Eleven children with an average age of 9 years old participated in the study. Elbow's kinematics and muscular activity at two resistances during flexion and extension of 7 children without CP (fig. 2) and 4 children with CP were acquired (fig. 3). Children with CP had a modified Ashworth score of 1, two children showed right hemiplegia and two showed diplegia.

Maximum joint angular flexion velocity was 300°/s and 450°/s for healthy children and CP children respectively. Maximum joint angular extension velocity was 550°/s and 400°/s for healthy children and CP children respectively. Muscular activity was categorized in four joint angle categories (0°-50°, 50°-70°, 70°-80°, >80°), and four joint angular velocity categories (0°/s-5°/s, 5°/s-19°/s, 19°/s -60°/s, >60°/s) to identify at least a mean difference of 2%±1.5% with a statistical power of at least 90%±5%. Categorized values of mean normalized sEMG envelopes of each muscle are shown in Fig. 4.

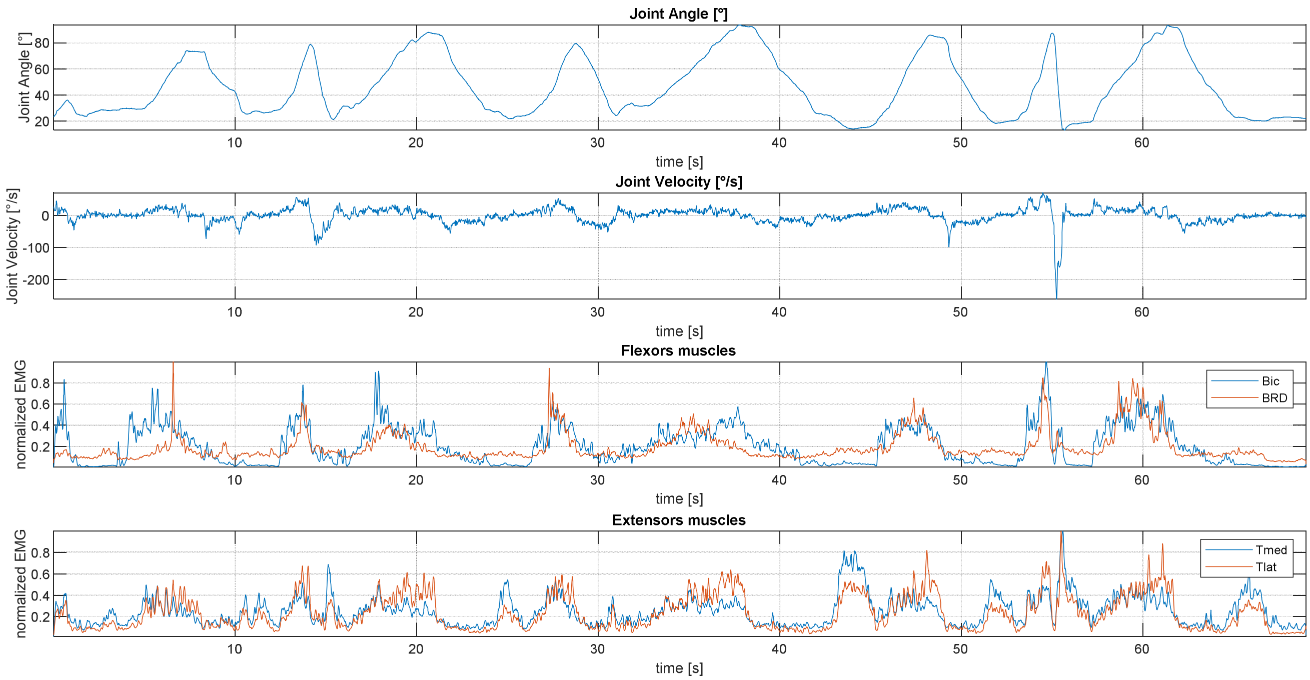

Figure 2. Example of aata adquired from one children without CP at 0.5kg load flexion resistance. First row: elbow's joint angle; second row: joint angular velocity; third row: muscular activity of flexor muscles (Bic: biceps and BRD: brachioradialis); fourth row: muscular activity of extensor muscles (Tmed; triceps medialis and Tlat: tricpes lateralis).

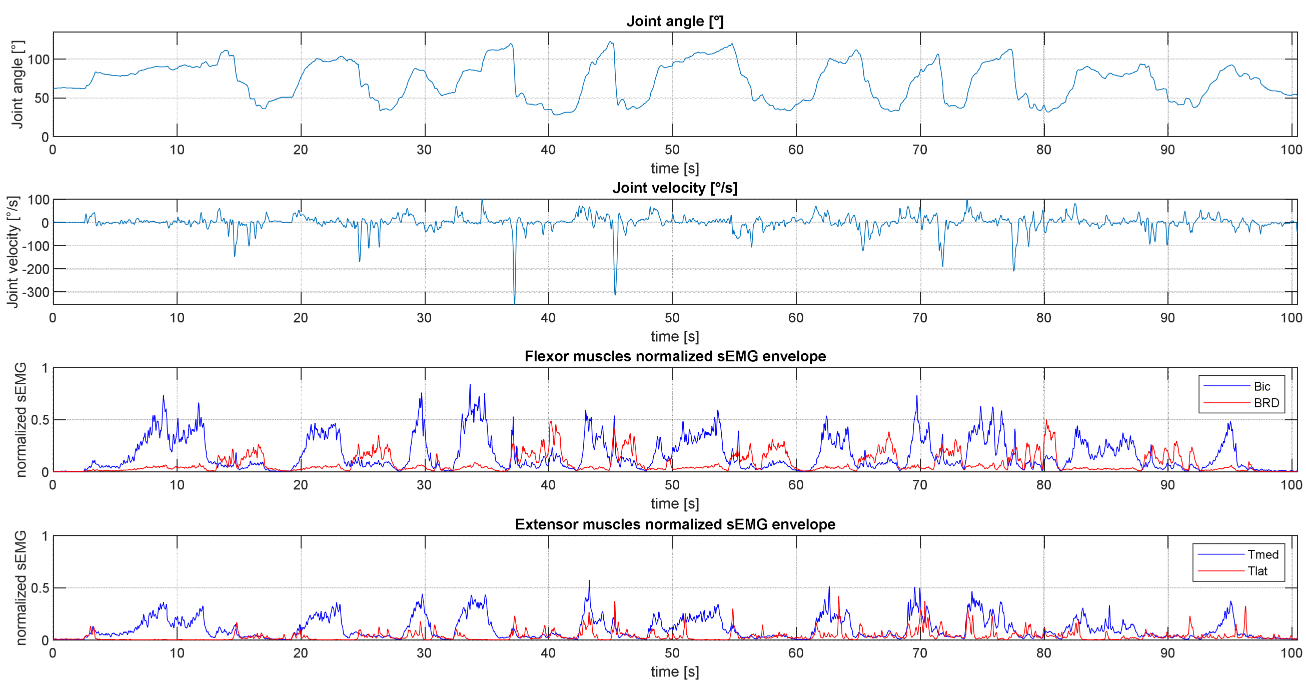

Figure 3. Example of aata adquired from one children with CP at 0.5kg load extension resistance. First row: elbow's joint angle; second row: joint angular velocity; third row: muscular activity of flexor muscles (Bic: biceps and BRD: brachioradialis); fourth row: muscular activity of extensor muscles (Tmed; triceps medialis and Tlat: tricpes lateralis).

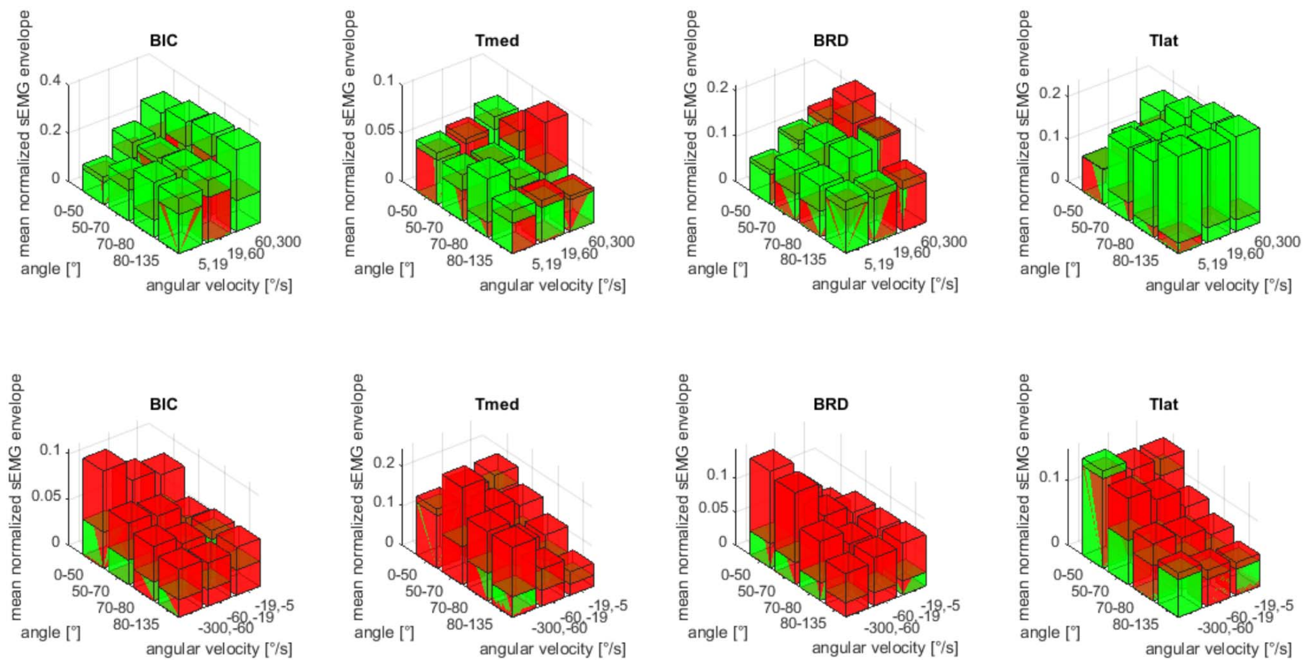

Figure 4. Categorized values of mean normalized sEMG envelopes of each muscle (Bic: biceps; BRD: Brachioradialis; Tmed: triceps medialis; Tlat: triceps lateralis). Upper row are categories for flexion with 1kg resistance. Botton row are categories for extension with 1kg resistance. Green color are mean normalized sEMG envelopes of healthy children. Red color are mean normalized sEMG envelopes of CP children.

In general, an increasing muscle activity with increasing joint angular velocity was observed.

Three-way ANOVA tests showed main and mixed effects for 1)group, 2)load, 3)contraction type, 4)joint position and 5)joint angular velocity for each muscle on the normalized sEMG envelope ($p<0.01$). Linear regressions of normalized sEMG envelope and velocity result on a mean root mean squared error (RMSE) of 0.07±0.05 and a mean coefficient of determination (R2) of 0.06±0.07. Slope of linear regressions of normalized sEMG envelope and velocity at joint angle between 50° and 70° are shown in TABLE I and Fig 5. ANOVA tests showed only main effects of group on the slope of linear regressions of normalized sEMG envelope and velocity ($p<0.01$). In general, slope of linear regressions of normalized sEMG envelope and velocity were bigger in CP children.

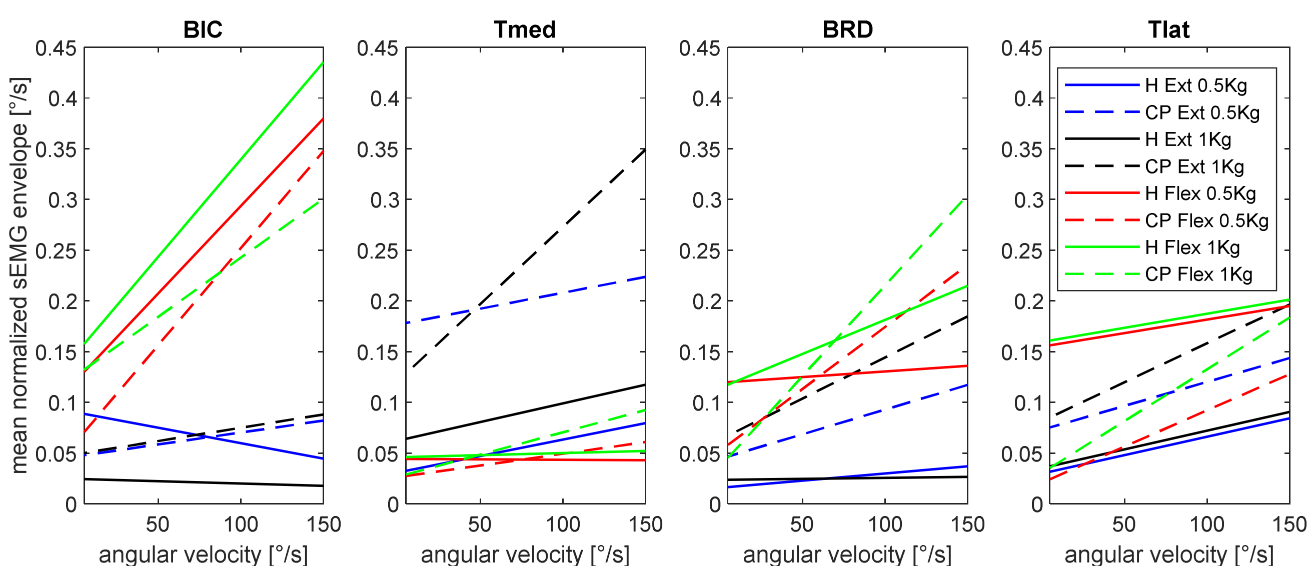

Figure 5. Linear regressions of normalized sEMG envelope and velocity at joint angle between 50° and 70° for healthy children (H) and CP children (CP) of each muscle (Bic: biceps; BRD: Brachioradialis; Tmed: triceps medialis; Tlat: triceps lateralis). at flexion (flex) and extension (ext) movements.

TABLE I. SLOPE OF LINEAR REGRESSIONS OF NORMALIZED sEMG ENVELOPE AND VELOCITY AT JOINT ANGLE BETWEEN 50° AND 70°

Load	Group	Bic	Tmed	BRD	Tlat
Ext 0.5kg	Healthy	-0.0003	0.0003	0.0001	0.0004
	CP	0.0002	0.0003	0.0005	0.0005
Ext 1kg	Healthy	< -0.0001	0.0004	< 0.0001	0.0004
	CP	0.0003	0.0015	0.0008	0.0008
Flex 0.5kg	Healthy	0.0017	< -0.0001	0.0001	0.0003
	CP	0.0019	0.0002	0.0012	0.0007
Flex 1kg	Healthy	0.0019	< 0.0001	0.0007	0.0003
	CP	0.0012	0.0004	0.0018	0.0010

Even though load showed no statistically significant effects on slope of linear regressions ($p>0.05$), an increasing slope was found for higher loads. Most slopes of linear regressions of normalized sEMG envelope and velocity were positive. However, a negative slope was found for biceps during extension movements and triceps medialis during flexion movements in healthy children.

IV. DISCUSSION

Previously, controversial results have been obtained while comparing muscular activity of children with muscular activity of adults during low force movements. While previous results have shown a clear increasing pattern of muscle activation with increasing angle velocities and joint angles for healthy adults [4] no clear pattern has been observed in healthy children[14].

Low resistance movements allow study of both load bearing and fine-tuning or stabilization function of a muscle in healthy children and children with a neuromusculoskeletal condition. Load bearing has been previously defined as the situation when a muscle generates a force which opposes to an external force while fine-tuning function was defined as the situation when an antagonistic muscle generates a force in line with that external force, resulting in stabilization of the movement [4]. During this experiment movement was successfully performed by both healthy and CP children using loads of 0.5kg and 1 kg. Even CP children showed muscular alterations they were able to perform elbow joint kinematics similarly to healthy children. An increment on resistance of 0.5kg was enough to evoke changes in muscular activity of children with and without CP.

Non-linear joint position and velocity categories allowed precise and reliable identification of differences on mean normalized sEMG envelopes for each muscle. Joint angular velocity categories can be used to analyze elbow joint kinematics at static (0°/s-5°/s), low (5°/s-19°/s), medium (19°/s -60°/s) and high velocity (>60°/s).

As expected, 1)group, 2)load, 3)contraction type, 4)joint position and 5)joint angular velocity had a statistically significant influence on the normalized sEMG envelope ($p<0.01$) [4]. Although some studies had imply that children can show unmatured neuromuscular strategies which result in differences in muscle control respect to adults[14], in our study groups no difference of children to adults or between healthy and CP children were observed. Therefore all previously mentioned factors can have a substantial effect on motor control which should be considered to improve the use of these information for diagnosis and treatment of neuromusculoskeletal conditions[1][2].

Increase of joint muscular activity at increasing joint velocity previously observed in adults during load bearing tasks [4] was also observed in both groups of children (with and without CP) in all muscles (biceps, brachioradialis and triceps). That is muscular activation increased.

During fine-tuning tasks at elbow extension, brachioradialis of healthy children performs the stabilizing action at high joint angular velocities in a similar way to healthy adults. On the other hand, muscle activation of biceps in healthy children decreases with increasing joint angular velocity, allowing faster joint movement. Similarly, during fine-tuning tasks at elbow extension, muscle activity of triceps medialis of healthy children decreases with increasing angular velocity. However, muscular activation of triceps lateralis differs. These results agreed with previous results which found differences on muscular activity between heads of triceps brachii during motion of the arm[5]. It was shown that lateral head has a significantly lower force than medial head, which also has a more uniform force distribution[5].

During fine-tuning tasks in CP children, muscle activation of biceps during elbow extension increases with increasing joint angular velocity, which could increase rigidity of elbow joint and could explain alterations of movement in CP children. Also, during fine-tuning tasks at elbow flexion, muscle activation of triceps medialis increases.

Differences between healthy and CP children found on the slope of linear regressions of normalized sEMG envelope and velocity and no statistically significant effect found for different muscle and load conditions, suggest a common muscle coordination mechanism for healthy children which could be altered in CP children. In our previous results, we found based on a time-frequency analysis in healthy children, a decoupling of activity of muscles antagonistic and agonistic in order to achieve high velocity motion[6].

Despite quality of results allowed us to identify at least a mean difference between muscular activity categories of 2% with a statistical power of 90%, this discriminative capacity could be increased by increasing sample size. Also, in order to investigate relying causes of differences on muscular control a subgroup analysis on a bigger sample including children with CP with higher compromise could be performed, correlating results with clinical measures of muscular force, joint spasticity and joint stiffness.

V. CONCLUSIONS

In this study we found evidence based on a time analysis of muscular activity of healthy children which helps to confirm the presence of a common muscle coordination mechanism suggested before based on time-frequency analysis, but we also found differences on that mechanism in children with CP. A high coupling of opposite muscles during pathological movement seems to be related to neuromuscular alterations such as involuntary muscle coactivation, loss of muscle control and increased joint stiffness in CP children[9][10]. Slopes of linear regressions of normalized sEMG envelope and velocity were higher in CP children which could also be related to muscle weakness and muscle atrophy [9][10].

The present work constitutes a novel description of muscular activity in relationship to joint position, joint speed, joint resistance, and type of contraction on children with CP, which may be used for diagnosis and treatment of neuromusculoskeletal conditions.

REFERENCES

[1] M. A. Ali, K. Sundaraj, R. B. Ahmad, N. U. Ahamed, M. A. Islam, and S. Sundaraj, "Muscle Fatigue in the Three Heads of the Triceps Brachii During a Controlled Forceful Hand Grip Task with Full Elbow Extension Using Surface Electromyography," J. Hum. Kinet., vol. 46, no. 1, pp. 69–76, 2015.

[2] S. Becker, S. C. F. A. von Werder, A. K. Lassek, and C. Disselhorst-Klug, "Time-frequency coherence of categorized sEMG data during dynamic contractions of biceps, triceps, and brachioradialis as an approach for spasticity detection," Med. Biol. Eng. Comput., vol. 57, no. 3, pp. 703–713, 2019.

[3] R. Meattini, G. Palli, and C. Melchiorri, "Experimental evaluation of a sEMG-based control for elbow wearable assistive devices during load lifting tasks," IEEE Int. Conf. Rehabil. Robot., pp. 140–145, 2017.

[4] S. C. F. A. von Werder and C. Disselhorst-Klug, "The role of biceps brachii and brachioradialis for the control of elbow flexion and extension movements," J. Electromyogr. Kinesiol., vol. 28, pp. 67–75, Jun. 2016.

[5] E. Kholinne, R. F. Zulkarnain, Y. C. Sun, S. J. Lim, J. M. Chun, and I. H. Jeon, "The different role of each head of the triceps brachii muscle in elbow extension," Acta Orthop. Traumatol. Turc., vol. 52, no. 3, pp. 201–205, 2018.

[6] A. I. Perez Sanpablo et al., "Position-Velocity Categorization of Time-Frequency Coherence for the Analysis of Muscle Coordination Dynamics of Elbow Joint during Low Force Movements in Healthy Children," in 2018 15th International Conference on Electrical Engineering, Computing Science and Automatic Control, CCE 2018, 2018, pp. 1–6.

[7] L. Bar-on, M. M. Vand der Krogt, A. I. Buizer, K. Desloovere, J. Harlaar, and L. H. Sloot, "Motorized versus manual instrumented spasticity assessment in children with cerebral palsy," pp. 145–151, 2016.

[8] "Programa de Prevención y Rehabilitación de Discapacidades. PreveR – Dis, Programa Nacional de Salud 2001 – 2006."

[9] L. Bar-On, E. Aertbeliën, G. Molenaers, B. Dan, and K. Desloovere, "Manually controlled instrumented spasticity assessments: A systematic review of psychometric properties," Dev. Med. Child Neurol., vol. 56, no. 10, pp. 932–950, 2014.

[10] F. Vivancos et al., "Guía del tratamiento integral de la espasticidad," Rev. Neurol., vol. 45, no. 6, pp. 365–375, 2007.

[11] A. M. Azab, M. Arvanch, and L. S. Mihaylova, "Version : Accepted Version Estimation of Joint Angle Based on Surface Electromyogram Signals Recorded at Different Load Levels . In : 2017 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). 39th Annual I," 2017.

[12] H. J. Hermens, B. Freriks, C. Disselhorst-Klug, and G. Rau, "Development of recommendations for SEMG sensors and sensor placement procedures," J. Electromyogr. Kinesiol., vol. 10, no. 5, pp. 361–374, Oct. 2000.

[13] S. C. F. A. Von Werder; Kleiber, T.; Disselhorst-Klug, "A method for a categorized and probabilistic analysis of the surface electromyogram in dynamic contractions," Front. Physiol., vol. 6, no. UNSP 30, 2015.

[14] E. Romero Avila et al., "sEMG-based differentiation of muscular activation patterns in children and adults during elbow movements," Biomed. Eng.-Biomed. Tech, vol. 63, no. S1, p. S241, 2018.