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Oral Abstracts

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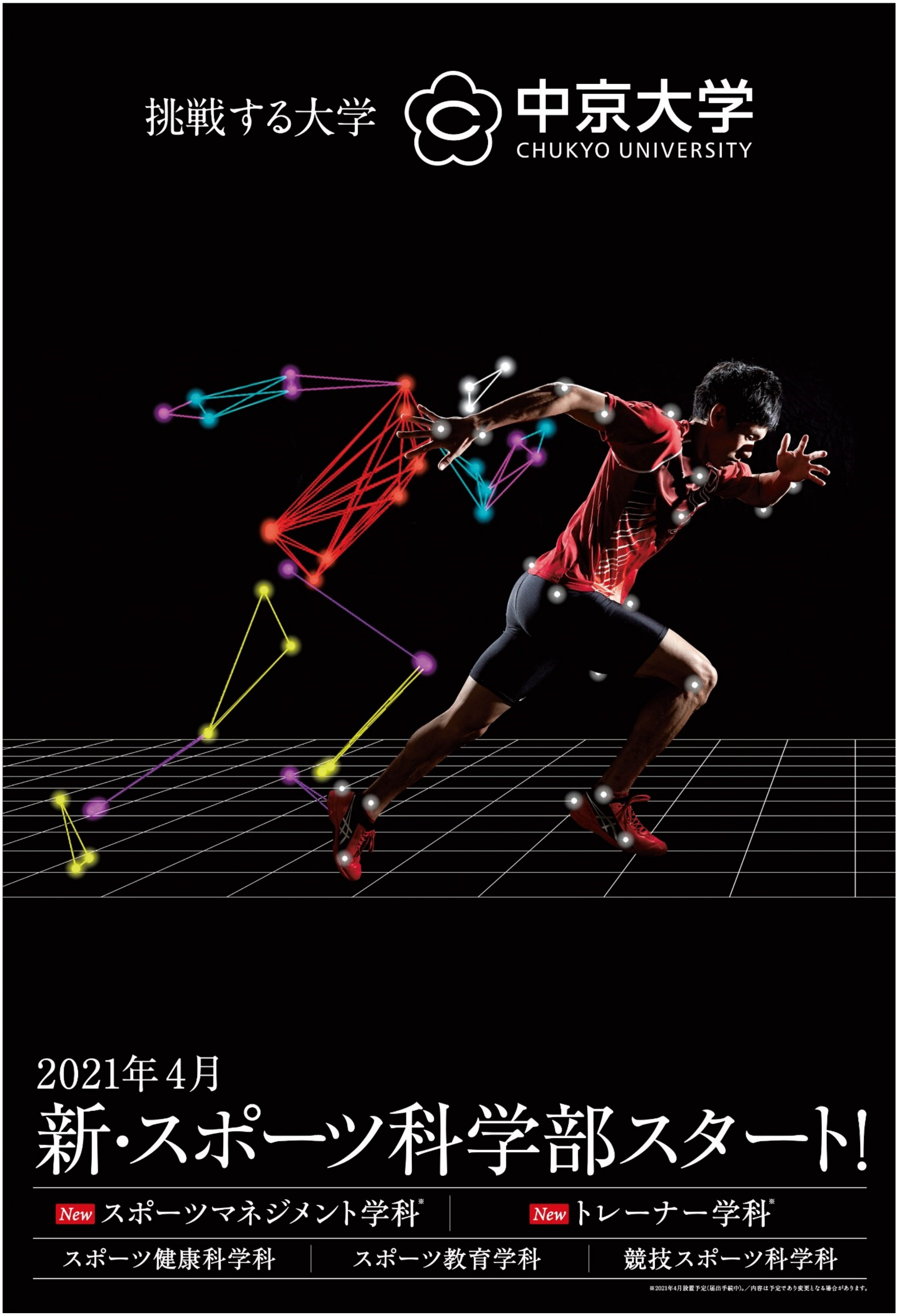
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KEYNOTE PRESENTATIONS

Basmajian Award Lecture

The elixir of muscle activation and kinesiology in a health perspective

Giseja Sjøgaard, University of Southern Denmark

Basmajian stated in his paper: “The elixir of laughter in rehabilitation” that “everyone advocates cheerfulness on the part of the healing professions” despite lacking evidence. Likewise, evidence was missing of exercise training at the worksite alleviating musculoskeletal pain, although everyone since Hippocrates advocates that physical activity benefits health. Muscle activation and movements performed during work tasks are on the contrary frequently reported to result in work-related musculoskeletal disorders. Therefore, we posed the research question: which mode of muscle activation may result in a reversal of work-related disorders? To address this, we performed electromyographic (EMG) and kinematic assessments of workers with diverse exposure: repetitive monotonous tasks (surgeons, musicians, sewing-machine and computer workers), prolonged walking/standing (cleaning personnel, meat cutters, and industrial workers) and heavy high intensity loading (military helicopter crew and firefighters). The various job-specific exposure variables could be categorized in terms of duration, intensity, static component, peak force etc. that were subsequently identified as risk factors. Based on sports science principles we developed tailored exercise programs to counteract job exposure overloading. EMG activity during exercise training was monitored to identify principal differences between exercise training and job patterns. Further, we revealed the effects in 17 RCT studies including >3500 workers. We found positive effects as decreased muscle pain and increased workability. Finally, we identified plausible underlying mechanisms in muscle tissue – human and animal – that confirmed metabolic, morphological, and hormonal changes with e.g. repetitive work that were reversal to adaptations reported with exercise training. Progress has been made in developing intelligent physical exercise training as the best complementary activity to job exposure and includes muscle activations and movements that limit work-related inactivity atrophy as well as overload tissue injuries.

Keynote Lecture Tetsuo Fukunaga

Estimation of mechanical work done during sprint running by means of 50m long force-platform system

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Japan National Institute of Fitness and Sports

Sprint running from a stationary state inevitably involves a period of time until the running velocity reaches the maximum, i.e. the acceleration stage. In this stage, runners are required to maximally accelerate their bodies to attain a high running velocity within a short period. Thus, examining the mechanics of the acceleration stage of maximal sprint running is essential to elucidate how runners are capable of achieving a high power movement. To realize this, it is necessary to continuously obtain data on kinetics and/or kinematics at each step during the entire period of maximal sprint running from the start of the run, because these markedly vary with increasing running velocity (Nagahara et al., 2014, 2018).

Many studies calculated the work done and/or power generated during running by analyzing the ground reaction force (GRF) during the stance period (Cavagna,1975). In previous studies,the work done at every step in running has been divided into two parts on the basis of the horizontal anterior–posterior GRF during the stance period: the work done during the braking phase (negative work) and propulsive phase (positive work), in which the runner's body decelerates and accelerates, respectively (Cavagna er al., 1971). The present study aimed to elucidate the magnitude of the mechanical work done in each of the braking and propulsive phases during the acceleration stage of 50 m maximal sprint running and the associations of the work variables with running performance. To this end, we adopted a newly developped 50 m force plate system (Nagahara et al., 2018) to continuously obtain GRFs at every step during the acceleration stage.

At 80% maximum velocity (Vmax) or higher, the positive work largely decreased and negative work abruptly increased. The change in the difference between positive and negative work, namely effective work, for acceleration the body at every step was relatively small at 70% Vmax or lower. Total work done over 50 m was 82.4±7.5 J /kg for positive work, 36.2±4.4 J /kg for negative work. The total effective work over 50 m was more strongly correlated with the running time for 50m ($r=-0.946$, $P<0.0001$) than the corresponding associations for the other work variables. These results indicate that in maximal sprint running over 50 m, work done during the propulsive phase in the horizontal anterior–posterior direction accounts for the majority of the total external work done during the acceleration stage, and maximizing it while suppressing work done during the braking phase is essential to achieve a high running performance.

Keynote Lecture Glen Lichtwark

Linking muscle-tendon mechanics to our understanding of human movement control

Glen Lichtwark, University of Queensland

Textbooks teach the basic anatomical and physiological properties of both muscles and tendons that play a role in governing the limits on human and animal performance. However, the neuromusculosketal system is complex and must also operate within a specific mechanical environment with varying task demands (e.g. force, work, power, precision). Understanding which factors are most important for how we control movement becomes complex in different scenarios. Complex computational models provide valuable tools to better understand the complexity, but a lack of knowledge of the fundamental basis by which the nervous system controls movement, limited information about individual muscle properties of muscles and simplistic models of muscle contraction currently reduce their predictive capacity.

In this presentation, I will outline a program of research that has been aimed towards better understanding the interaction between muscle-tendon mechanics and neural drive required to perform movements (predominantly in the lower limb). I will outline the methods we have used to characterise muscle-tendon mechanical function and provide evidence for the important role that tendinous tissue compliance plays in dictating the control strategies we use for movements. I will also provide specific examples of how characterising muscle-tendon interaction can provide explanations for why muscle excitation patterns are often not easy predict (e.g. when activation levels remain the same or even reduce, despite the force requirements of muscles increasing).

Finally, I will consider some of the current problems and challenges in how we view muscle-tendon mechanics. These challenges need to be overcome to generate accurate models or simulations of movement that can be used to have impact in areas of rehabilitation, sports performance or even prosthetic design. Some of these challenges include how we consider the aponeurosis of the muscle to operate mechanically, heterogeneity in muscle architectural features (including sarcomere length along the muscle) and problems with our current imaging techniques that need to be addressed to provide more accurate experimental data.

Keynote Lecture Toshio Moritani

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SUNTORY

Electrical Muscle Stimulation: Application and potential role in aging society

Toshio Moritani, University of Kyoto

Neurodegenerative diseases and sarcopenia become more prevalent as individuals age and, therefore, represent a serious issue for the healthcare system. Several studies have reported the relationship between physical activity and reduced incidence of dementia or cognitive deterioration. Thus, exercise and strength training are most recommended treatments, but it is proving difficult to engage individuals to initiate exercise and strength training. Electrical muscle stimulation (EMS) may provide an alternative and more efficient solution. Although EMS has undergone a decline in use, mainly because of stimulation discomfort, new technologies allow painless application of strong contractions. Such activation can be applied in higher exercise dosages and more efficiently than people are likely to achieve with exercise. Unlike orderly recruitment of motor units (MUs) during low intensity voluntary exercise, EMS activates large fast-twitch MUs with glycolytic fibers preferentially and this could have benefit for prevention and treatment of diabetes and chronic diseases associated with muscle atrophy that ultimately lead to bed-ridden conditions. Recent evidence highlights the potential for EMS to make a major impact on these and other lifestyle related diseases and its role as a useful modality for orthopedic and cardiac rehabilitation. This talk will discuss the potential for EMS to break new ground in effective interventions in these frontiers of medical science.

Keynote Lecture Janet Taylor

What is the neuro in neuromuscular fatigue?

Janet Taylor, Edith Cowan University

Whenever we carry out strenuous, sustained or repetitive physical activity the performance of our motor system progressively declines. Muscle fibres produce less force and the nervous system becomes less able to drive the muscle maximally. Spinal motoneurones are the final neural component in the motor pathway and their firing is the culmination of many processes within the nervous system. Thus, there are multiple mechanisms that can contribute to make motoneurone firing insufficient to generate maximal muscle forces. First, the motoneurones themselves can become less excitable when they fire repetitively. Second, excess serotonin released onto motoneurones via descending fibres from the medulla can act via receptors at the axon initial segment to inhibit motoneurone firing. Conversely, reduced serotonin release during longer duration exercise may hinder the motoneurones' ability to fire repetitively. Third, sensory feedback from the fatigued muscles, via the small-diameter muscle afferents that fire in response to metabolites, can inhibit some motoneurone pools. Finally, descending drive from the motor cortex to the motoneurones can become suboptimal. Fatigue-related sensory feedback is an important influence on cortical output as well as at a spinal level, and also contributes to the sensations of muscle work, fatigue and pain. The different neural mechanisms of fatigue probably differ in importance with different kinds of exercise, both because they develop at different rates and because they alter task-dependent motor output in different ways. For example, it is easy to see the consequences of fatigue during maximal muscle contractions, when force and power are reduced, whereas during submaximal tasks, compensatory changes in voluntary drive can maintain performance, but this comes at the cost of more effort.

ORAL PRESENTATION SESSIONS

Session Aging 1

A1-1: Surface EMGs features to differentiate between saliva and water based on single swallowing events.

Carlotta Malvuccio[1]
[1]*King's College London*

BACKGROUND AND AIM: The incontrovertible fact which our society is facing nowadays is the increase in population aged 65 and over. According to a UN source (2019), by 2050 one in six people in the world will be aged over 65, and the number of persons aged 80 years and over to triple. While this is due to societal improvements in lifestyle and advances in technology and healthcare, it will soon pose new challenges if action is not taken to advance the technology we currently possess as elders necessitate more care and medications. One such flaw in our healthcare system is posed by dehydration, which particularly concerns older adults. With the vision of an automatic fluid monitoring system, this study investigates features of the surface EMG (sEMG) that can be used to discriminate saliva from fluid intake. METHODS: The sEMG signals for both suprahyoid and infrahyoid group of 11 subjects (3 females, 8 males, mean age 27ą13.42) were recorded. Subjects were instructed upon command to perform three saliva swallows, five sips from a cup, straw, plastic bottle and a sip of water with volume equal to the largest volume being swallowed with an additional 5 ml. Weights of the containers were recorded before and at the end of each sip to enable the calculation of the amount of fluid being swallowed during each recording. The sequence of the tasks was randomised for each subject. Recordings were then processed in MATLABŪ. A bandpass filter with a bandpass frequency range of 20-400 Hz was applied to eliminate components which do not hold significant anatomical information and a Teager-Kaiser Energy Operator (TKEO) which allowed to identify and differentiate between segments of the signal containing swallowing bursts and noise. Four features were then applied to the burst and noise segments, namely Root Mean Square (RMS), Mean Absolute Value (MAV), Waveform Length (WL) and Willison Amplitude (WAMP). Principal Component Analysis (PCA) using the singular value decomposition algorithm was then applied to such features. A fine Gaussian SVM classifier was also used for the detection rate of swallowing events. RESULTS: Using the first two principal components, applied to each subject, there is a clear difference between noise, saliva and water (See Fig. 1 for a representative subject). Furthermore, the classifier had an average detection rate accuracy of 99.53%. CONCLUSION: These results provide the potential of an optimum classifier. REFERENCES:United Nations, Department of Economics and Social Affairs (2019). World Population Prospects [online]. United Nations. [Viewed 21 November 2019]. Available from: https://www.un.org/development/desa/publications/world-population-prospects-2019-highlights.html

A1-2: Effect of old age on fatigue-induced changes in muscle activation, oxygenation, and thickness during intermittent, dynamic elbow flexion exercise

Christopher Bailey[1], Julie Côté[1]
[1]McGill University

BACKGROUND AND AIM: Old age has been associated with greater muscle fatigue in dynamic elbow flexion tasks, usually quantified by decreased maximal torque production and/or increased muscle activity. Development of fatigue, however, also prominently features disrupted muscle oxygenation and increased muscle thickness (swelling); how old age affects the time course of these concurrent responses is not fully clear. METHODS: Fifteen young females (23.3 ą 3.1 years) and ten old females (62.8 ą 6.9 years) completed repeated trials of an intermittent elbow flexion task with an isokinetic dynamometer (Contrex?). Each trial consisted of a 60-second bout of 60°/s concentric/eccentric repetitions at 20% maximal voluntary isometric contraction (MVIC), a 30 second rest, and a MVIC; trials were repeated until MVIC torque was < 70% of baseline. Performance fatigability was defined by the number of trials completed. Surface electromyography (EMG) sensors measured biceps brachii (BB) and brachialis (BRA) muscle activation during each bout, with amplitude outcome quantified by the root mean square (RMS). A near-infrared spectroscopy (NIRS) sensor measured BB oxygenation during bouts, and B-mode ultrasonography was used to measure BB and BRA muscle thickness (MTH) during inter-bout rests. An independent t-test was conducted to test for an Age effect on the number of trials completed. General estimating equations were conducted on RMS, NIRS parameters, and MTH to test for effects and interactions of Age, Trial (Baseline (for NIRS and MTH), first, 50%, final), and Muscle (for RMS and MTH). MAIN RESULTS: There was no difference in the number of trials completed by young (11 ą 8) and old females (10 ą 7) (p = .892). BB and BRA RMS increased in the first half of the task in young and old females and again in the second half of the task but only in young females (A*T*M: p = .008). BB concentrations of total, oxygenated, and deoxygenated hemoglobin were greater in young than in old females (A: p = .009-.019). In both age groups, oxygen saturation decreased from baseline to the first trial but recovered to baseline by the final trial (T: p = .001), and oxygenated hemoglobin decreased at the first trial and further decreased by the final trial (T: p = .001). BB MTH increased in old females but not in young females and BRA MTH increased in the first half of the task in young and old females and again in the second half of the task but only in young females (A*T*M: p = .011). CONCLUSIONS: Old females hit a plateau in the increase in muscle activation and BRA swelling, had lower concentrations of hemoglobin, and had BB swelling, compared to young females. Collective results indicate that old age influences the time course of the physiological response in dynamic elbow flexion fatigue, even without a difference in performance fatigability.

A1-3: Age- and sex-specific effects in paravertebral surface electromyographic muscle fatigue recorded from chronic low back pain patients participating in a cyclic back exercise

Gerold Ebenbichler[1], Richard Habenicht[2], Paolo Bonato Bonato[3], Josef Kollmitzer[4], Patrick Mair[5], Thomas Kienbacher[2]

[1]Vienna Medical University, [2]Karl Landsteiner Institute for Outpatient Rehabilitation Research, [3]Harvard Medical School, [4]School of Engineering, [5]Harvard University

Background and aim: Whereas old age and female sex are associated with comparatively lower back extensor muscle fatigability, back muscle fatigue is typically increased with chronic low back pain (cLBP). This study sought to investigate whether or not surface electromyographic representations recorded during a cyclic back extension exercise would - like in healthy individuals - be marked by age- and sex-specific differences. Methods: A total of 221 (111 females) cLBP patients performed a series back extension tests that comprised of three maximal isometric back extensions (MVC), followed by an isometric back extension at 80% MVC, and finally 25 slow cyclic back extensions at 50% MVC. SEMG data was recorded bilaterally from the iliocostalis lumborum (L1), longissimus (L2), and multifidus muscles (L5), respectively. Tests were repeated two days and six weeks later. A linear mixed-effects model investigated for age-specific differences in both the initial value and the time-course (as defined by the slope of the regression line) of the root mean square (RMS-SEMG) values and instantaneous median frequency (IMDF-SEMG) values calculated separately for the shortening and lengthening phases of the exercise cycles. Results: Maximum back extensor strength was significantly higher in men than in women but comparable between younger and older cLBP patients. Except for a significant RMS-SEMG decrease observed for the electrode demonstrating the most negative IMDF-SEMG fatigue slope, the RMS-EMG changes significantly increased with the duration of the cyclic exercise with no significant age- or sex-specific differences observed for this variable. By contrast, the IMDF-EMG fatigue slopes recorded from the concentric phases of the exercise revealed significantly less decrease in older than younger cLBP patients in L5 (multifidus), L2 (longissimus), and the most negative fatigue slope electrode recording sites. Furthermore, IMDF-SEMG fatigue was more pronounced in males than females at L5 and the electrode demonstrating the most negative SEMG fatigue slope. Age- and sex-specific differences in IMDF-SEMG changes were also observed for the eccentric phases of the cyclic exercise, but these were overall less pronounced. Conclusions: Like with healthy individuals, the IMDF-SEMG time-course derived from submaximal, cyclic back extension exercises performed at moderate effort showed significant differences in younger vs. older cLBP patients, even though back extension strength was found to be comparable between the two age groups. We conclude that the SEMG method proposed in this study has great potential to be used as a biomarker to detect early signs of sarcopenic back muscle function before major back muscle weakness becomes overt.

A1-4: The acute effect of ankle weight on regional activity of rectus femoris and lower extremity kinematics during walking in older adults

Shideh Narouei[1], Aya Tomita[1], Hiroyasu Akatsu[2], Kohei Watanabe[1]
[1]Chukyo University, [2]Nagoya City University

BACKGROUND AND AIM: Rectus femoris muscle activity is important to induce optimal demanded force during swing in older adults. Ankle weight is a traditional usable method to increase neuromuscular activity during dynamic actions. Although the previous studies showed that rectus femoris has different regional activation in older adults, the effect of ankle weight on regional neuromuscular activation of rectus femoris across gait phases is not well understood. We hypothesized that using ankle weight increases the activity of proximal region of rectus femoris (RFP) and improves lower extremity kinematics during walking. The aim of this study was to investigate the acute effect of ankle weight on regional activity of rectus femoris and lower extremity joint angles during walking in older adults. METHODS: Twenty-nine healthy older adults (67.9 ą 6.8 years) walked at normal gait speed in two trials with and without ankle weight (0.5-2 kg) for each leg on a treadmill. Each trial was 150 sec and the interval rest was 5 min. Neuromuscular activity of RFP and distal region of rectus femoris (RFD) and lower extremity kinematics were measured using surface electromyography (EMG) and motion capture, respectively. We analyzed ten consecutive gait cycles in left lower extremity. Averaged rectified values (ARV) of RFP and RFD were normalized by maximum values of ARV during a gait cycle. RESULTS: ARV of RFP were not significantly increased with using ankle weight more than without weight ($p>0.05$). ARV of RFP during terminal stance and mid-swing phases were significantly more than ARV of RFD using ankle weight ($p<0.05$). Also, hip flexion during mid-stance and mid-swing with ankle weight was increased more than without weight ($p<0.05$). Knee extension during mid-stance and initial- swing with ankle weight was increased more than without weight ($p<0.05$). Moreover, Ankle dorsiflexion in pre swing with ankle weight was increased more than without weight ($p<0.05$). CONCLUSIONS: These findings show that ankle weight could change neuromuscular activity pattern of RFP and improve lower extremity kinematics during walking in older adults. Keywords: Older_ Ankle weight_ Proximal and distal regions of rectus femoris _ Surface electromyography _ Joint angle_ Gait

A1-5: Changes of kinematic synergy in older adults during walking: a two-year follow-up study

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[1]Kyoto University, [2]Fukui General Clinic

BACKGROUND As walking posture during single support (SS) phase becomes unstable with a small base of support especially in the frontal plane, the control of center of mass (CoM) by segmental coordination is crucial. We applied uncontrolled manifold (UCM) analysis to evaluate how the segmental coordination stabilizes CoM. UCM hypothesis assumes that the central nervous system organizes kinematic variability at the level of elemental variables (e.g., segmental angles) to stabilize the performance variable (e.g., CoM during walking). Within the analysis, the strength of kinematic synergy can be quantified by a synergy index; the greater synergy index indicates more flexible coordination pattern of segments to keep CoM stable during walking. Our previous study found the association between the synergy and the future fall during walking (Yamagata M. J Biomech. 2019), but there is no study to clarify how the synergy index changes using longitudinal study. We explored whether the synergy index in older adults would be changed with normal aging. METHODS Twenty community-dwelling older adults participated in a baseline visit. The subjects walked on a 6-meter walkway 10 times at their self-determined comfortable speed, and kinematics data were collected with VICON motion systems. Data were time normalized from right toe-off to right initial contact (0-100%), and CoM trajectories were evaluated from marker data. With UCM analysis, we calculated a synergy index from two components of variance; one is VUCM, which does not affect the CoM trajectory, and the other is VORT, which affects the trajectory. For further statistical comparisons, the CoM displacements and synergy index were averaged within three intervals, 0-33% (early-SS), 34-67% (mid-SS), and 68-100% (late-SS). Timed Up and Go (TUG) test, maximum knee extensor strength, and gait speed were also assessed as the physical characteristics. The above-mentioned variables were evaluated after 2-year follow-up as well as at baseline. Paired t tests were performed each phase to determine the differences in the CoM trajectories and synergy index between baseline and follow-up. We also used paired t tests for physical characteristics. The significance level was set at 0.05. RESULTS Thirteen older adults were included in follow-up data (65%). During mid-SS, the synergy index at follow-up was significantly greater than that at baseline, although there were no significant changes in the CoM trajectories. Regarding the physical characteristics, TUG time at follow-up was significantly longer than that at baseline. No significant differences were observed in gait speed and knee extensor strength. CONCLUSION Despite the similar CoM trajectories, the segment configurations to make CoM stable was changed in 2 years; the synergy index was increased at follow-up. Given the longer TUG time, the greater kinematic synergy to keep the CoM trajectory stable could be one of strategy to compensate for the physical function decline.

Session Biomechanics 1

B1-1: Postural Adjustment Influence on Endurance Performance Enhancements

Naira Campbell-Kyureghyan[1], Blake Johnson[2], En Yi Wu[2]
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BACKGROUND AND AIM: A learning effect can confound results from studies that use a performance-based outcome in exercise. Subjects that are able to learn to adapt to the test to increase performance can result in the subsequent biomechanical data being difficult to interpret. By adapting their performance strategies during repeated testing subjects are able to improve performance without changing their underlying biomechanical processes. It is hypothesized that one of these strategies is postural adjustments. METHODS: Eight subjects were asked to perform a fatiguing isotonic knee flexion/extension task using a Biodex system over the course of 4 days (each trial was separated by 24 hours). The muscle activity of the Vastus Lateralis (VL), Vastus Medials (VM), and Rectus Femoris (RF) where collected. A pressure map was placed on the seat and back of the Biodex chair to measure pressure distribution. The pressure measured for each of the legs were summed separately and the length of the trial was measured as an indicator of endurance (time to fatigue - TTF). The number of flexion/extension cycles and rate (cycles per seconds) were also calculated. RESULTS: Three out of eight subjects showed consistent increases in endurance across days while 2 out of the eight subjects were observed to have consistent endurance decreases and the remaining subject results varied with each day. A total of 5 trials were observed to be influenced by rate where an increase in rate resulted in a decrease in TTF and vice versa. Subjects who slowed down conserved energy and were thus able to last longer and those who increased their speed tired out faster than the previous day. The remaining trials were influenced by the vastus lateralis muscle activity. A positive Spearman correlation coefficient of 0.36 was found between an increase in VL muscle activity and increases in TTF. One explanation for the VL increase association with an increase in TTF were due to the postural changes the subjects adopted in order to increase their flexion/extension output. Subjects that increased their asymmetric seat pressure profile to favor the opposite leg increase their TTF. A strong Spearman correlation of 0.69 was found between the TTF changes across days and pressure map distribution changes across days. This shows that subjects adapted to the exercise by pushing off the seat of the Biodex with their opposite side to aid in the knee extension portion of the task. Utilizing the opposite side as leverage pushed the tested knee slightly in the lateral direction which results in the increased VL muscle activity. CONCLUSIONS: Overall endurance performance outcomes cannot always be easily explained only through the investigation of muscle activity. Postural adjustments in task performance can influence the results and confound the muscle activity measurements.

B1-2: Sex Differences in Shoulder Muscle Activation and Fatigue among Elite Water Polo Players

Lily Dong[1], Savannah King[1], Julie Côté[1]
[1]*McGill University*

BACKGROUND AND AIM: The shoulder is the most common site of injury in water polo. Fatigue of the shoulder girdle has been proposed as a mediator between muscle imbalances, repetitive movements, and injury. Since female athletes in overhead sports may be especially vulnerable to shoulder injuries, this study investigated sex differences in throw velocity, strength, and neuromuscular parameters of the shoulder before and after fatigue. METHODS: Eleven female (79.95ą14.07 kg) and fifteen male (94.21ą10.79 kg) elite water polo players were recruited. Using an isokinetic dynamometer (CON-TREXŪ MJ), participants performed concentric maximal voluntary contractions (MVCs) of external and internal rotation at 90° of arm abduction, followed by five seated maximal water polo ball throws. The protocol was repeated after a fatiguing task consisting of concentric shoulder internal rotations at 50% MVC with passive external rotation. Ball speed and MVC torque were measured and electromyography amplitude root-mean-square (RMS) and median power frequency (MdPF) were calculated from surface electrode recordings of pectoralis major (PEC), anterior deltoid (AD), posterior deltoid (PD), upper trapezius (UT), and middle trapezius (MT). Functional connectivity was determined using the normalized mutual information (NMI) from the signals of muscle pairs. Generalized estimating equations were used to assess main effects of fatigue and sex and their interactions. RESULTS: Both men and women reached fatigue, demonstrating significant declines in ball velocity and a 5.6% and 7.6% drop, respectively, in peak internal rotation torque. The men also produced 10.1% less torque during the external rotation MVCs after the fatiguing task. Regardless of fatigue state, men generated higher MVC peak torque and ball speed than women and had 37.3% higher values of PEC RMS during the throws, while women had 41.5% higher values of AD RMS during the throws. Men and women showed similar decreases in RMS and MdPF in AD and PD during MVCs after the fatiguing task, but had different responses in UT and MT, notably with men displaying a greater decrease than women in MT RMS and an increase in MT MdPF. After fatigue, both groups had similar changes in NMI between muscle pairs (main fatigue effect for MT-UT, $p = 0.007$), though women exhibited more increases in NMI than men (interaction effect for AD-UT, $p=0.022$). CONCLUSION: Men and women differ in more than just force production capacity. Though they displayed some similarities in their force- and fatigue-related electromyographic responses, the two sexes may have different motor strategies that influence how they perform high-intensity overhead tasks and, consequently, how they are differentially affected by - or compensate for - shoulder muscle

fatigue. This information could help elucidate sex-specific risk factors for injuries in overhead sports such as water polo.

B1-3: Exercise with blood-flow restriction reduces time to failure, induces more pain, but generates the same neuromuscular fatigue as free-flow exercise

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BACKGROUND AND AIM: Strength training performed with low external loading (LL) and partial blood-flow restriction (BFR) has been shown to be an effective training method promoting gains in neuromuscular function (e.g. maximal muscle strength) and skeletal muscle growth. However, the mechanism behind the increased function and muscle growth with blood flow restriction is still unclear and there is a lack of data on the microvascular tissue oxygenation and neuromuscular fatigue with partial BFR and free flow (FF) exercise performed at LL to task failure. The aim of the present study was to examine the acute effect of BFR on muscle activation and oxygenation of the vastus medialis (VM) and vastus lateralis (VL) muscles during a single bout of unilateral knee extension to task failure. METHODS: The study was designed as a within-group randomized cross-over study design with BRF and FF. Participants performed unilateral knee extensions at 20% of one-repetition maximum to task failure, using a BFR or a FF protocol in randomized order on two separate days. Changes in oxygenation and neuromuscular activation of VL and VM were assessed using near-infrared spectroscopy (NIRS) and surface electromyography (sEMG), respectively. Pain measures were collected using visual analogue scale (VAS) prior and following task failure. Within- and between-group comparisons were performed at multiple time points of normalized set completion for each muscle. RESULTS: Participants were 17 male participants aged 26.2 (2.2) years , with BMI of 25.8 (2.8) and with 1 RM values of 66.2 (11.6) kg. During BFR the participants performed 43% fewer repetitions and pain scores increased more (5.5 ą 2.0) compared to FF (4.0 ą 2.0) ($p<0.05$). Normalized to time to task failure, BFR and FF generally demonstrated a similar progression in neuromuscular activation and oxygenation during exercise to task failure. For VM, a time x protocol interaction showed a higher EMG amplitude in FF compared to the BFR protocol ($p=0.044$) while no time x protocol interactions were observed for VL. Oxygenation decreased at all time points in both muscles (VL, VM) in both BFR and FF exercise protocols ($P\leq0.001$) and at task failure there was no difference between the two protocols. CONCLUSION: The present results demonstrate that the progressive increase in sEMG-activity and decrease in tissue oxygenation are generally similar during FF and BFR at any given timepoint normalized to task failure. For oxygenation there was no difference between the two protocols However, compared to the FF protocol BFR induces more pain and requires less contractions to reach the same level of neuromuscular fatigue indicated by increased muscle activation.

B1-4: Activation differences in the equine biceps femoris muscle during right hand and left hand walk and trot in an automated horse walker

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BACKGROUND AND AIM: Horses routinely exercise on automated horse walkers; however, there is no research evidence on their muscle activity patterns during this. Working on a circle, the inner limbs move on a smaller radius than the outer limbs, and horses have to maintain and coordinate the different activities of inside and outside muscles. In this, the biceps femoris (BF) muscle plays an important role to support the vertical orientation of the hindlimb and as an abductor muscle generating turning forces. Therefore, the current study aims to document the muscle activity pattern changes of BF in right hand and left hand walk and trot in an automated horse walker. METHODS: Nine adult horses (7 to 14 years of age, body mass 470 to 590 kg) freely walked and trotted at their optimal speed in an automated horse walker (20 m diameter) for 20 minutes. Activation of left and right BF muscle was collected using surface electromyography sensors (Delsys Trigno Avanti, Delsys Inc, Natick, MA) at approximately halfway between the third trochanter and patella and 6 cm cranial to the cranial margin of the semitendinosus muscle. Signal processing steps for each stride included high-pass filtering (Butterworth 4th order, 40Hz), then low-pass filtering (Butterworth 4th order, 20Hz) and normalisation relative to the observed third-quartile sEMG values. The results of BF muscle activity were expressed as relative percentages of median values to these third quartile values and were compared during walk and trot in both directions. Comparison of the inside and outside limb muscle activity of BF was carried out during the start of the walk trial (warm-up phase), middle of the walk trial (mid-phase), during trot and at the end of the walk trial (cooling down phase). RESULTS: Results showed more muscle activity (on average plus 18 %) of outside compared to inside muscles during the start of the walk trial in 10/18; during the middle of the walk trial in 10/18; during the trot trial in 6/18 horses and during the end of the walk trial in 8/18. Statistical results indicated significant differences of the use of the BF on the inside and on the outside limbs when walking and trotting in a circle during the middle trials. CONCLUSION: Moving on a circle horses lean in towards the centre of the circle and change tension in the soft tissues of the limbs, thus it was expected in the current study that inside and outside muscle activities also differ. Overall, these pattern differences might be even more enhanced between the inside and the outside muscle, if the horses were more restricted in their position relative to the curve of the circle.

B1-5: Per-step and cumulative loading rate in unilateral transfemoral amputees at various walking speeds

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BACKGROUND AND AIM: Unilateral transfemoral amputees (uTFAs) are exposed to a high risk of musculoskeletal disorders, such as degenerative joint diseases, due to repetitive impulsive loading.

Although per-step vertical instantaneous loading rate (VILR) is used to evaluate the risks of musculoskeletal disorders, it cannot assess the repetitive load accumulation during walking for a given distance (e.g., 1 km). Understanding the cumulative VILR at various walking speeds can provide practical information to reduce the repetitive impulsive loading in their daily lives. The aim of this study was to evaluate the per-step and cumulative VILRs in the unaffected and affected limbs of uTFAs at various walking speeds. <p> METHODS: Twenty uTFAs and 20 non-amputees walked at 8 speeds (2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, and 5.5 km/h) on a split-belt force-instrumented treadmill, where the vertical ground reaction force was recorded at 1000 Hz. We calculated the per-step VILR as the maximum instantaneous slope of the vertical ground reaction force from the foot contact to the first peak. Furthermore, the cumulative VILR was calculated by multiplying per-step VILR by the number of steps required to walk 1 km. The number of steps was calculated by dividing the distance by stride length. As the variables were not normally distributed, Kruskal-Wallis and Friedman tests were used to investigate the main effect of limbs and speeds, respectively. In case of significance, a Mann-Whitney U test and a Wilcoxon singed-rank test were used for post-hoc comparisons. Statistical significance was set at $P < 0.05$. <p> RESULTS: There was a statistically significant effect of limbs on per-step VILR ($P < 0.01$, Figure 1), and the per-step VILR in the unaffected limb was significantly greater than that in the other limbs at all speeds. However, there was no significant difference between the per-step VILR in the affected and control limbs at any speed. There was a significant effect of speed on per-step VILR ($P < 0.01$), and the per-step VILR in the all limbs increased between 3.0 km/h and 5.5 km/h speed. We also found a significant effect of limbs on cumulative VILR ($P < 0.01$), where the cumulative VILR in the unaffected limb was significantly greater than that in the other limbs at all speeds, but there was no significant difference between the cumulative VILR in the affected and control limbs at all speeds. There was also significant effect of speeds on cumulative VILR ($P < 0.01$). Overall, the cumulative VILR in the unaffected and affected limbs constantly increased between 3.5 km/h and 5.5 km/h speed. <p> CONCLUSIONS: The results of the per-step and cumulative VILRs suggest that the unaffected limb of uTFAs is exposed to a greater risk of musculoskeletal disorders than the affected and control limbs of non-amputees. Since cumulative VILR of unaffected and affected limbs increased at 3.5 km/h, the uTFAs should walk at <3.5 km/h speed to avoid excessive loading in their daily life.

B1-6: Whole-body sagittal plane angular momentum during walking in unilateral transfemoral amputees

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BACKGROUND AND AIM: More than half of unilateral transfemoral amputees (UTFAs) are reported to fall at least once each year. For continuous walking without falls, the whole-body angular momentum about body center of mass should be regulated to maintain the dynamic balance. Generally, the range (peak-to-peak of time variation) of whole-body sagittal plane angular momentum is greater than the transverse and frontal planes during human walking. The greater range of whole-body angular momentum would lead to the greater risk of falling, since a greater external moment is required to restore whole-body angular momentum (Sepp et al., 2019). However, little is known about the regulation of whole-body angular momentum in UTFAs. Thus, the aim of this study was to evaluate the sagittal plane dynamic balance using whole-body angular momentum during walking in UTFAs. <P>METHODS: Fourteen UTFAs and 14 non-amputees performed level walking at a self-selected speed on a straight 10-m walkway. All UTFAs used their habitual prosthetic components during the experiment. Three-dimensional positional data was collected using reflective markers and a three-dimensional motion capture system. Ground reaction force was also recorded using force plates. Whole-body sagittal plane angular momentum was calculated using a 15-segment model (head, torso, pelvis, upper arms, forearms, hands, thighs, shanks and feet). All the variables were averaged across the five trials to serve as the representative values for each participant. Independent t-tests were performed to check the statistical differences in the range of whole-body angular momentum between UTFAs and non-amputees. The range of whole-body angular momentum was calculated as the peak-to-peak value through the whole phase, first half, and second half of the affected limb's gait cycle. The significance level was set at p-value less than 0.05 for each analysis. <P>RESULTS: The range of whole-body sagittal plane angular momentum was greater in UTFAs compared to non-amputees through the whole phase ($p = 0.019$) and first half ($p = 0.035$) of the affected limb's gait cycle (Fig. 1). However, there was no significant difference in the range of whole-body sagittal plane angular momentum between two groups ($p = 0.140$) in the second half of the gait cycle. <P>CONCLUSIONS: UTFAs had the greater range of whole-body angular momentum compared to non-amputees in the sagittal plane. Our results suggest that UTFAs would have a greater risk of falling in the sagittal plane, especially during the first half of the affected limb's gait cycle.

Session Biomechanics 2

B2-1: Validation of a novel device for horizontal weight-bearing for dynamic computer tomography: A surface EMG study

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BACKGROUND AND AIM: Important advancements have been made in dynamic computed tomography (4DCT). Research on the wrist joint has shown possible applications to identify ligament injuries [1]. Preliminary research has been also conducted on the lower limb, but all studies have investigated the lower limb in a non-weight-bearing condition. The aim of this study is to validate a device developed to simulate weight-bearing during a horizontal squat movement and to identify the optimal load for clinical studies in medical imaging. METHODS: 20 healthy volunteers (age: 26 ą 6 years) were enrolled for this study. Each participant performed 8 series of 6 orthostatic squats (OS) with the back sliding against the wall and 6 horizontal squats (HS) on a newly developed device. The device had a platform, a moving component where the subject lies on and a loading system that provided the needed resistance. Eight different resistances based on body weight percentage (BW%: 30, 35, 37, 40, 42, 45, 50, 55) were selected randomly. Surface electromyography (sEMG) were acquired. A wireless 8 channels bioPLUX unit with a sampling frequency of 1000 Hz was used. The muscles assessed by sEMG were: Rectus Femoris

(RF), Bicep Femoris (BF), Tibialis Anterior (TA) and Gastrocnemius Lateralis (GaL), bilaterally. Maximum Voluntary Contraction (MVC) was recorded before the start of the experiment. The EMG signal was filtered using Savinsky-Golay filter and smoothed. The peaks, representing maximal activation for each repetition, were combined using root mean square values. sEMG was then expressed in percentage of MVC and Intraclass Correlation Coefficient (ICC) and difference between OS and HS were calculated. Averages between right and left leg were subsequently computed. RESULTS: ICC (3,1) values ranged between 0.68 and 0.72 for the BF, between 0.41 and 0.57 for the RF, between 0.48 and 0.66 for the TA, and between 0.49 and 0.89 for the GaL (Table 1). The highest average ICC of 0.68 and 0.67 were found for BW% 42 and 45 respectively with an absolute difference between OS and HS of 8.7% (Table 2). CONCLUSIONS: Compared to orthostatic squats performed in a standing position, the newly developed device was able to replicate squats in a horizontal position with a good level of accuracy and small differences in sEMG activity of the muscles of the lower limb. Using our device and based on maximum muscle activation during a set of repetitions, a BW% between 42 and 45 is recommended to replicate orthostatic squats. Adopting such device for weight-bearing simulation during dynamic CT scanning, may open new possibilities for the diagnosis of lower limb pathologies. 1. White et al. The use of 4D-CT in assessing wrist kinematics and pathology. Bone Joint J 2019, 101-B(11):1325-1330

B2-2: Can Kinematics of the lower limb be reproduced in horizontal potion for dynamic computer tomography imaging? Validation of a new weight-bearing device

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BACKGROUND AND AIM: Performing movements of the lower limb in an open or closed kinetic chain and with or without weight-bearing, influences joint kinematics. So far, all studies investigating the lower limb with dynamic computed tomography (4DCT) occurred without weight-bearing and closed kinetic chain movements. This may have an important impact on the interpretation and usability of the results. In order to fill this gap, we investigated a new device to simulate weight-bearing during dynamic CT acquisition in a horizontal position. METHODS: 20 healthy volunteers participated in this study. Each participant performed 8 series of 6 orthostatic squats (OS) with the back sliding against the wall and 6 horizontal squats (HS) on the device. The device had a platform, a moving component where the subject lies on and a loading system that provided the needed resistance to perform HS. Based on body weight percentage (BW%: 30, 35, 37, 40, 42, 45, 50, 55), eight different resistances were randomly selected. 3D kinematics of both hips, knees, and ankles were captured by a 6-cameras VICON MX F20 system (250 Hz). For each joint, the Euclidean norm of the 3 angles was calculated and average between right and left computed. The rotational angles normalized by time were compared between OS and HS, and this for both hips, both knees and both ankles. For each BW%, at three different time intervals of the motion (0-10%, 10-85% and 85-100%), the Standard Error of Measurement (SEM) was computed as a measure of reliability between OS and HS. Results were displayed as means and 95%CI's across the whole time interval. RESULTS: Figure 1a,1b,1c show SEM between the OS and HS for the hip, knee, and ankle joint. For the 10-85% motion interval, a load of 42 BW% resulted in the lowest SEM for hip and knee. At the level of the ankle, OS and HS were most similar for a load of 55 BW%. For the motion intervals of 0-10%

and 85-100%, loads had no impact on the SEM between OS and HS. Average angle differences between OS and HS did not exceed 5˚ for nearly all BW% (Figure 1d). CONCLUSIONS: 42 BW% appears to be the most accurate load to be used with our device to simulate hip and knee kinematics of an orthostatic squat in a horizontal position. 55 BW% may be the best load to be adopted to simulate ankle motion. This novel device may open new possibilities to investigate lower limb pathologies in weight-bearing using 4DCT.

B2-3: Changes in length-force relationship of muscle-tendon complex due to stiffness of tendinous tissue -Finite element simulation-

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In experimental studies, it has been reported that the stiffness of tendinous tissue (aponeurosis + tendon) correlates with the sport's performance. In this study, using finite element simulation, we investigated the effect of stiffness of tendinous tissues on the ability of muscle-tendon complex to exert force. The developed software (V-Biomech, RIKEN) for finite element analysis of biological tissues with non-linear large deformation model was used. A 3 dimensional tetrahedral constitutive mesh model of unipennate muscle (200 mm length) including muscle fibers with pennation angle, and tendinous tissues was constructed. Mechanical properties of tissues were set using Mooney-Rivlin material models. Model for muscle tissue also have contractile characteristics of activation process as well as force-length-velocity relationship for force generation. Simulation with three different mechanical parameters of tendinous tissues (stiff [1], normal [2] and compliant [3]) were performed, then length - force relationship of muscle-tendon complex was evaluated. The length showing the peak of the length-force relationship of the muscle-tendon complex was the shortest for stiff (-10mm), medium for normal (0mm), and longest for compliant (30mm). The peak value at that point was higher in the order of stiff, normal and compliant (697.3N, 459.5N and 301.1N, respectively). This result suggests that stiffer tendinous tissues is advantageous in maximal force production (e.g. by 2.3 times than compliant tendinous tissues). In addition, the results of strain distribution in mesh model showed the tendency that contractile elements in muscle tisuues became shorter in more compliant model in many cases. This caused weak force production in the contractile elements, since contractile element should generate force within ascending limb in length-force relationship of muscle tissues. This study demonstrated the possibility that stiffer tendinous tissues would have great advantage in force production even in same mechanical and physiological properties in muscle tissues, by altering of strain distribution of muscle tissues longer. 1. Rosager S, et al., Scand J Med Sci Sports 12: 90-98, 2002. 2. Reeves ND, et al., J Appl Physiol. 98: 2278-2286, 2005. 3. Shin D, et al., J Appl Physiol.105: 1179-1186, 2008.

B2-4: The influence of verbal instructions on EMG activity at coactivations sets

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BACKGROUND AND AIM: The coactivation or co-contraction is a promissory method postulated as an alternative to traditional strength training. Characterized by a simultaneous contraction of agonist/antagonist muscles with no requirement of external load/equipment, the coactivation training demonstrated increases in EMG activity during maximal voluntary contractions. It also showed similar activity levels when compared to conventional strength training. Some methods seem to improve muscular performance along with strength training. The mind-muscle connection, for example, increases EMG activity on target muscles during conventional exercises of strength training using attentional focus to a determined movement or a specific muscle group contraction. However, the mind-muscle connection was not tested in conjunction with coactivation training yet. Therefore, we aimed to test if verbal instructions offered to the practitioner to direct attentional focus throughout coactivations sets, could modify the neuromuscular activity of elbow flexors and extensors muscles. METHODS: Eighteen trained males (25.22ą5.23 y.o., 81.51ą12.32 kg, 178.06ą7.83 cm) warmed up (two sets of 20 submaximal repetitions) for elbow flexion and extension on a dual adjustable pulley. Following the warm-up, two coactivation sets were performed. Each coactivation set consisted of five coactivations (four seconds of effort and four seconds of rest), controlled by a metronome app. Throughout the coactivation sets, the participants seated keeping arms by the trunk, elbows flexed at 90š, and wrist in a neutral position. Along with the set, specific verbal instruction was given to the participant. On each set, the verbal instructions were, "During this set, imagine that you are going to flex your elbow, but do not move the elbow" or "During this set, imagine that you are going to extend your elbow, but do not move the elbow." The order of these verbal instructions was given in a counterbalanced way. Between each set, there was a 10-minutes passive interval. During each set, the participants were verbally encouraged to make the maximum effort and also not to move other joints. After that, the participants rested five minutes to perform three maximum voluntary isometric contractions (MVIC) of five seconds for both elbow extension and elbow flexion on a dual adjustable pulley. Electromyographic data were collected from biceps brachii (BB), triceps brachii lateral (TBLat), and long head (TBLong) of the dominant limb. The EMG signals were filtered using a 4th order Butterworth digital bandpass filter (10-500Hz). The RMS value of each muscle was normalized by dividing mean activity from the coactivations by the mean processed signals collected during the MVIC. RESULTS: The BB showed difference (p=0.001) between verbal instruction focusing on elbow flexion (68.74%ą17.95) vs. verbal instruction focusing on elbow extension (53.47%ą16.12). For the TBLat there was no difference (p=0.302) between verbal instructions (elbow flexion: 66.15%ą16.58; elbow extension: 70.25%ą21.62). Finally, for the TBLong the results also showed no difference (p=0.509) (elbow flexion: 72.57%ą13.16; elbow extension: 75.35%ą6.48) (figure 1). CONCLUSIONS: The use of different verbal instructions depending on objective produces different EMG activity. Therefore, it is indicated for strength coaches the use of verbal instructions to emphasize target muscles during coactivations, especially for the BB muscle.

B2-5: Ultrasound quantification of uterine motion patterns in relation to in-vitro fertilization

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BACKGROUND AND AIM Partially due to the trend to postpone childbirth, about one in six couples experience infertility problems in their reproductive lifetime. In-vitro fertilization (IVF) is today the most advanced assisted reproductive technology. In Europe alone, it represents the last resort for over 2.5 million couples with infertility problems. Unfortunately, the failure rate of IVF treatment remains higher than 70%. There is evidence of a major involvement of uterine motion in IVF outcome, but solutions for uterine motion analysis are lacking. We propose a dedicated method for quantification of the uterine motion pattern by speckle tracking in B-mode transvaginal ultrasound (TVUS). The method is tested for its ability to distinguish between the different phases of the menstrual cycle and, ultimately, to predict successful embryo implantation during an IVF cycle. METHODS Speckle tracking is implemented by block matching. Singular-value-decomposition filtering is tuned to extract the uterine-motion components. Speckle tracking is further accelerated by a diamond search. The method feasibility was first tested in 9 healthy women at the Catharina Hospital Eindhoven, the Netherlands. 4-min TVUS scans were acquired in each woman at 4 different phases of the menstrual cycle by a WS80A scanner (Samsung) equipped with a transvaginal V5-9 probe. Motion and strain are calculated along the longitudinal and transversal direction of the uterus in the sub-endometrial layer. Frequency and amplitude features are extracted from these signals and evaluated (two-tailed Student's t-test) for their ability to discriminate between active and quiescent phases. In addition, velocity and direction of the peristaltic waves are assessed along the longitudinal direction of the uterus. To this end, time-space analysis is implemented in the k-space by detection of the dominant spectral peaks. Next to the healthy women, 16 women were analyzed during their IVF cycle at the University Hospital Ghent. The extracted features were evaluated as predictors of successful IVF outcome (embryo implantation). RESULTS Among the considered features, median and contraction frequency show significant difference ($p<0.05$) between active (late follicular) and quiescent (menses and late luteal) phases. The contraction frequency also shows the ability to distinguish between successful and unsuccessful embryo implantation ($p<0.05$) already before embryo transfer. CONCLUSIONS Although more extensive validation is required, our results show the feasibility of uterine motion/strain quantification, providing a valuable tool to improve clinical decision making in IVF procedures.

Session Clinical Neurophysiology 1

CN1-2: Long-term treatment with bipolar pulsed electromagnetic fields increases movement speed and erythropoietin in Parkinson

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BACKGROUND AND AIM: Parkinson's disease (PD) is characterized by motor dysfunctions including bradykinesia. Specific motor deficits such as reduced rate-of-force development and impaired

coordination and balance contribute to slow movement speed in patients with PD, which constitutes a challenge for daily activities. In a recent study eight weeks of daily transcranial stimulation with bipolar pulsed electromagnetic fields (T-PEMF) improved functional rate-of-force development in patients with mild PD (1). The aim was to investigate the effect of long-term (3x8 weeks) treatment with T-PEMF on motor performance in terms of movement speed and on neurotrophic and angiogenic factors. METHODS: Patients diagnosed with idiopathic PD had either a daily 30-min treatment with bipolar T-PEMF (ą50 V, squared pulses, 3ms duration) (Re5, NTS-Parkinson-Treatment-System, Denmark) (2) for three eight-week periods separated by one-week pauses (n=14, age: 66.6 yrs., disease duration: 6.2 yrs.) in addition to their regular pharmacologic treatment or were included in a PD-control group (n=8, age 70.5 yrs., disease duration 5.5 yrs.) following their regular pharmacologic treatment. Movement speed was assessed in a six-cycle sit-to-stand task performed on a force plate (AMTI, 120x90 cm, USA). Cerebrospinal fluid from the intervention group was collected and analyzed for erythropoietin. RESULTS: Major significant improvement of movement speed compared to the natural development of the disease was found (p=0.001). Thus, completion time decreased gradually from 10.10s (SD 2.41s) at week 0 to 8.23s (SD 1.78s) post treatment (p<0.001). The PD-control group did not change (p=0.458). The treated group did not differ statistically from that of a healthy age matched reference group at completion of treatment. Erythropoietin concentration in the cerebrospinal fluid increased significantly in the treated group (p=0.012, n=8). CONCLUSION: Long-term treatment (3x8 weeks) with bipolar T-PEMF increased movement speed markedly. Sub-division of the sit-to-stand completion time into movement components indicated that the reduced sit-to-stand completion time was explained by shorter time periods throughout the movement cycle. Furthermore, the treatment elevated erythropoietin levels in the cerebrospinal fluid. We hypothesize that treatment with T-PEMF improved functional performance by increasing dopamine levels in the brain, possibly through erythropoietin induced neural repair and/or protection of dopaminergic neurons. References 1: Malling ASB, Morberg BM, Wermuth L, Gredal O, Bech P, Jensen BR. Effect of transcranial pulsed electromagnetic fields (T-PEMF) on functional rate of force development and movement speed in persons with Parkinson's disease: A randomized clinical trial. PLoS One 2018;13(9):e0204478. 2: Rahbek UL, Tritsaris K, Dissing S. Interaction of Low-frequency, Pulsed Electromagnetic Fields with Living Tissue: Biochemical Responses and Clinical Results. Oral Bioscience and Medicine 2005;2(1):1-12. Funding: The Jascha Foundation, Denmark; Den A.P. Møllerske Støttefond, Copenhagen, Denmark; and Grosserer L.F. Foghts Foundation, Charlottenlund, Denmark.

CN1-3: Isolated mixed effect of estradiol and progesterone on motor neuron excitability

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BACKGROUND AND AIM: There is a growing body of literature in animal models that recognizes the potential role of estrogen and progesterone may affect spinal circuitry in healthy and injured states. However, little is known about the effect of these hormones on the basic neurophysiological properties of the human motor neurons. METHODS: 20 eumenorrheic healthy young women participated in the study (age 29ą4 yrs, BMI 25ą4). Each subject was tested every other day for one menstrual cycle

with a randomized starting date. Blood sample determined the Estradiol (E) and Progesterone (P) levels. While the subject was lying pronate on a massage table, we administered an H reflex test by delivering a series of 2 ms monophasic pulse (1 mA increment) to the tibial nerve in the popliteal fossa using a pair of metal electrodes (d = 0.8 cm, distance 2.5 cm) until the peak-to-peak value (p2p) of the M wave reach its maximum value. A bipolar electromyogram (sampled at 2 kHz, 4th order Butterworth zero lag filter 10-350 Hz) was recorded from the medial soleus muscle using a pair of gel electrodes (d = 1 cm) following SENIAM recommendation. We confirmed electrodes pair were placed in the same position for all sessions. We calculated spinal motor neuron excitability as the ratio of maximum p2p of H wave to maximum p2p of M wave (H/M). Correlation analyses between the hormones levels and H/M were performed by the Spearman test. RESULTS: On average, the H/M values were similar across the three phases: menses, ovulatory (until peak E), and luteal (after peak E). However, in the luteal phase the H/M significantly has positive correlation with the concentration ratio E/P ($p<0.05$) while in the ovulatory phase the H/M do not correlate with the rising of E. CONCLUSIONS: Our pilot data indicate that while motor neuronal excitability was not affected by changes in estrogen concentration, increases in progesterone level were associated with a depression in motor neuron excitability in healthy young women. These findings may highlight the opposing effect progesterone may have on the inflammatory and the neurophysiologic states of the spinal cord.

CN1-4: Objective analysis and characterization of changes in the activity of single motor units in neuromuscular disorders using high spatial resolution electrmyography

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BACKGROUND AND AIM: Altered muscle structure, activation and control are characteristic of neuromuscular disorders. Stroke and autosomal-recessive spinal muscular atrophy (SMA) are neurogenic disorders while Duchenne muscular dystrophy (DMD) is a myogenic disease. These disorders all have a negative impact on voluntary, functional movement capability. Diagnostic testing in the case of SMA and DMD conventionally involved needle-electromyography, muscle biopsy, enzyme tests and genetic testing. In the case of stroke various imaging technologies may be employed for diagnosis, but giving no information about related changes within the muscles. Assessment of changes in muscular activation plays an important role in the classification and monitoring of neuromuscular disorders. While needle-EMG provides detailed temporal and spatial information regarding motor unit activity, it finds limited use in clinical monitoring. Conventional surface electromyography is non-invasive and painless but the electromyogram attained has limited spatial resolution and cannot show the activation of single motor units. High-Density EMG in combination with a Laplacian spatial filter (HSR-EMG) allows the non-invasive detection of motor unit action potentials (MUAPs). The aim of this study is the objective analysis and characterization of changes in the activity of motor units in neuromuscular disorders using HSR-EMG. METHOD: Motor unit behaviour in the following 4 subject groups was investigated using HSR-EMG: 61 healthy subjects (age group: 2 weeks - 25 yrs.), 21 patients with SMA (age range: 9 mths. - 16 yrs.), 35 patients with Duchenne muscular dystrophy (age range: 2 mths. - 22 yrs.) and 10 stroke patients (age range: 42 - 78 yrs.). For each subject, data was collected from the abductor pollicis brevis muscle of the dominant hand during 3 maximal voluntary isometric contractions of 1 second duration each. Data processing was based on 8 parameters: root mean square (RMS), signal entropy (H), first zero-crossing of the autocorrelation function (ZACF), dwell time over root mean square (DT), chi-squared value of the sample distribution (CHI), maximum amplitude of all MUAPs (MAM), gradient of MUAP slope (GMS) and centroid of the distribution of the maximal amplitudes of all MUAPs (CDM). Mean and standard deviation was calculated from the healthy subject group. 75% confidence interval was used to build a reference range for each parameter. Percentage of patients over and below the reference range were determined for each patient group. RESULTS: The results of the parameter-based analysis are summarized in Figure 1. RMS and H did not differentiate well either between the patient groups or between patients and healthy subjects. Values of CHI, GMS, MAM and CDM below the reference range and values of ZACF and DT above the reference range characterize patients with DMD. Patients with SMA can be clearly separated from healthy subjects by DT and CHI. Stroke patients can be distinguished from healthy subjects by the parameters RMS, ZACF, DT and CHI in which values of RMS and CHI are above the reference range and values of ZACF and DT are below. Differences between both neurogenic disorders can be found in the parameter values RMS and ZACF. DISCUSSION Using the parameters extracted from the HSR-EMG signals, healthy subjects can be distinguished from patients with neuromuscular diseases. Patients with myogenic disorders differ from patients with neurogenic disorders in parameters that describe the shape and size of the MUAPs. In patients with DMD, these parameters tend to indicate frequent but small, broad MUAPs of different sizes that are difficult to separate in the signal course. It has already been shown by modelling that this is a consequence of loss of muscle fibres [Disselhorst-Klug 1998]. In contrast to healthy individuals, the parameter values of SMA patients indicate that this disease manifests itself with few, large, isolated MUAPs that vary little in magnitude. This is a consequence of the loss of MUs associated with SMA. Like in SMA, there is a difference between the parameter values for DT and CHI between stroke patients and healthy subjects. However, in contrast to SMA patients stroke patients show lower ZACF values and higher RMS values than healthy subjects. This suggests that the HSR-EMG signal of stroke patients is characterized by more MUAPs firing more regularly compared to SMA patients. CONCLUSION: The two neurogenic disorders considered were characterized by fewer MUAPs. The stroke group showed MUAPs with lower variability than SMA. The HSR-EMG signals for the myogenic disorder, DMD showed very many small MUAPs that were difficult to distinguish in the signal course. This study has shown that the HSR-EMG is a suitable method for analysing disease-specific changes at the MU level. Furthermore, it is possible to quantify these changes on the basis of the parameters introduced.

CN1-5: Neuromuscular Assessment of Diabetic Myophaty

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BACKGROUND AND AIM: Muscle atrophy and reduced muscle function are commonly observed in people living with type 1 diabetes (T1D) especially when the disease is not well controlled. These alterations, often accompanied by pejorative changes in the metabolic and cellular machinery of the skeletal muscle (1), have been collectively termed diabetic myopathy(2). Moreover, whole-body fatigue is a frequent complaint in individuals living with T1D but it is unclear if this would depend on muscle alterations per se or on a concomitant impairment in motor units (MU) properties. The behavior of

populations of MUs can be now investigated, non-invasively, with high-density surface electromyography (HD-EMGs) using multi-channels electrodes (3). METHODS: Sixteen participants, 8 T1D (4M; 33.7 ą 5.2 yrs.; HbA1c 8.1 ą 3.1 %) and 8 Non-diabetic (Non-D) (4M; 31.5 ą 5.6 yrs.) volunteered to the present study. In one 2-hour visit to the laboratory participants were tested for maximal isometric strength (MVIC) of knee extensors (KE), short sustained KE isometric contractions at 20 and 40 % MVIC, plus a sustained contraction at 40% MVIC until task failure. During these measures we recorded HD-EMGs from vastus lateralis (VL) muscle with a grid of 64 electrodes in monopolar configuration. RESULTS: No differences, between the 2 groups, were observed in MVIC and rate of torque development. In addition, also the HD-EMGs responses were mostly similar between the two groups, and these included MU firing rate and muscle fiber conduction velocity (MFCV; a marker of MU recruitment). The only HD-EMG parameter which differed between the 2 groups was the coefficient of variation of the MUs inter-spike interval which was lower in T1D (12.0 + 7.3 %) than in the Non-D controls (22.7 + 10 %). In addition, and contrary to our expectations, we observed that after fatigue the MFCV was reduced in the Non-D ($p < 0.001$) but not in the T1D, participants. CONCLUSIONS: No major differences were detected between the two groups which could justify the presence of a diabetic myopathy in our T1D participants. Further studies are needed to build a more comprehensive profile for this condition possibly including the analysis muscle signaling properties and muscle fiber type distribution using muscle biopsies. REFERENCES: 1). Krause MP, Riddell MC, Hawke TJ. Review. Effects of type 1 diabetes mellitus on skeletal muscle: clinical observations and physiological mechanisms. Pediatric Diabetes. 2011(12):345-64. 2). Monaco CMF, Perry CGR, Hawke TJ. Diabetic Myopathy: current molecular understanding of this novel neuromuscular disorder. Curr. Opin. Neurol. 2017;30:545- 552. 3) Merletti R, Holobar A, Farina D. Analysis of motor units with high-density surface electromyography. J Electromyogr Kinesiol. 2008 Dec;18(6):879-90.

Session Fatigue 1

F1-1: Central fatigue arising from maximal voluntary contractions is exacerbated by enhanced serotonin availability

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BACKGROUND AND AIM: Animal preparations have revealed that intense release of serotonin (5-HT) onto the spinal motoneurones causes spillover of 5-HT to extrasynaptic 5-HT1A receptors on the axon initial segment to reduce motoneurone activity. The release of 5-HT is believed to be related to motor activity, where enhanced levels of motor activity correspond to greater levels of serotonergic drive to motoneurones. We performed two experiments to determine how increased extracellular concentrations of 5-HT affect the ability to perform sustained maximal voluntary contractions (MVC) in humans. METHODS: Each experiment was a double-blind, placebo-controlled, cross-over design. Paroxetine 20 mg was used to enhance 5-HT concentrations by inhibition of serotonin reuptake. In experiment 1, superimposed and resting twitches were obtained from biceps brachii via motor nerve

stimulation during a fatigue protocol (n = 11). Four sustained maximal elbow flexions were each performed until torque declined to 60% MVC (4 contractions, 40 s rest between contractions). Within 6 s after each contraction, a resting twitch was elicited and then a superimposed twitch during a brief MVC. Voluntary activation was calculated by comparison of the amplitudes of these twitches. Experiment 2 used supramaximal ulnar nerve stimulation to elicit F-waves from adductor digiti minimi (ADM) following a 2 s and a 60 s MVC (n = 8). F-wave persistence and area were used as a measure of spinal motoneurone excitability. RESULTS: Enhanced 5-HT availability did not affect twitch properties of the resting muscle, but decreased time-to-fatigue by 2.3 ą 3.8 s (p = 0.038) and voluntary activation of the biceps brachii by 2.6 ą 7.0% (p = 0.048) following repeated maximal elbow flexions. F-waves of the ADM were marginally affected following a brief 2 s MVC. However, F-wave area and persistence were significantly decreased by 19.0 ą 11.2% (p = 0.032) and 16.3 ą 9.1% (p < 0.001), respectively, following a prolonged 60 s MVC of the ADM. CONCLUSIONS: Enhanced 5-HT availability was associated with poorer motor performance as shown by shorter times for torque to drop to 60% MVC. The mechanisms underlying the decline in motor performance had neural origins as fatigue-related reductions in the resting twitch, which reflect peripheral fatigue, were unaffected by paroxetine, whereas reductions in voluntary activation were increased. Moreover, reductions in motoneurone excitability after a fatiguing MVC were also greater with paroxetine, which suggests a spinal mechanism by which 5-HT may contribute to central fatigue.

F1-2: Neck muscle fatigue impacts wrist joint position sense

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BACKGROUND AND AIM: Muscle fatigue can alter afferent feedback and influence joint position sense (JPS). Peripheral muscle fatigue impacts the sense of movement produced by muscle spindles, and subsequently, proprioception is affected. Previous work has demonstrated that neck fatigue can alter neck, shoulder and elbow JPS. However, there is a lack of evidence to suggest that neck fatigue also impacts the distal upper extremity. The aim of this study was to examine the effects of cervical extensor muscle (CEM) fatigue on wrist JPS in participants with and without subclinical neck pain (SCNP). METHODS: Twelve healthy and 12 SCNP patients volunteered. Participants placed their right forearm in a three-degrees-of-freedom wrist manipulandum (WristBot, Genoa, Italy) with their hand grasping the handle of the device. Using the robotic device, both groups performed a wrist JPS test (pre-fatigue), an isometric CEM fatigue protocol and a post-fatigue JPS test. Each JPS test consisted of 12 trials; 6-wrist flexion and 6-wrist extension of randomly selected joint angles. Wrist JPS was measured as the participants ability to recreate a previously presented joint angle. The robot passively moved the participants' hand to a random position, then passively moved the participant back to the neutral position. An auditory cue signaled the participant to actively move their wrist back to the previously presented target with no assistance from the robot. Participants were blindfolded and wore noise cancelling headphones during the session. Kinematic data from the robotic device measured matching error, variability and error bias. RESULTS: The average time to fatigue for the SCNP group was 10:00 ą 0.13 minutes and 12:42 ą 0.11 minutes for the control group. At baseline, the joint position matching error was significantly higher in SCNP (4.42 ą 1.32°) than controls (3.13 ą 0.42°; p=<0.05). Following

fatigue, matching error decreased from baseline in the SCNP group, and increased in the control group (SCNP = 3.88 ą 0.64°, control = 3.78 ą 1.12°). Error bias was significantly different for the SCNP group when compared to the control group (SCNP = -0.863 ą 1.06°; control = 0.773 ą 1.62°). CONCLUSION: This study demonstrates that altered afferent input from the neck (due to pain and/or fatigue) can influence wrist JPS. An opposite effect was found in direction of error between the groups. A negative error bias indicates an undershooting of the target in the SCNP group, and a positive error bias indicates an overshoot of the target in the control group. This altered proprioception can have significant consequences for upper extremity task performance.

F1-3: Prediction of prolonged decreases in maximal voluntary contraction strength by changes in neuromuscular parameters immediately after eccentric exercise of the knee extensors

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BACKGROUND AND AIM: Unaccustomed eccentric exercise (ECC) induces muscle damage that is best represented by a prolonged (>1 day) reduction in maximal voluntary isometric contraction (MVIC) strength. It is difficult to detect muscle damage immediately post-ECC, since the decrease in MVIC strength results from a combination of acute neuromuscular fatigue and peripheral muscle damage. It may be that the neuromuscular fatigue component can be isolated by quantifying central and peripheral neuromuscular parameters. The present study examined changes in MVIC strength at 24-72 h post-ECC in relation to changes in neuromuscular parameters immediately post-ECC. METHODS: Twenty participants (12M, 8F; 19-36 y) who were not resistance trained, performed ECC consisting of 6 x 8 contractions of the knee extensors at 80% of eccentric-1RM on an isoinertial leg extension machine. Rate of force development (RFD) was assessed during knee extensor MVIC. Femoral nerve and transcranial magnetic stimulations were used to assess twitch force (TF), maximal M-wave (Mmax), voluntary activation (VA), motor evoked potential (MEP) amplitude and short-interval intracortical inhibition (SICI) before, immediately after, and 24-72 h post-ECC. Pearson (r) or Spearman (rs) correlation tests for parametric and non-parametric data, respectively, were used to examine relationships between changes in MVIC at 24-72 h post-ECC and changes in other variables (RFD, TF, Mmax, VA, MEP, SICI) immediately post-ECC. RESULTS: MVIC decreased by -22.2ą18.4% immediately post-exercise, and remained below baseline at 24 (-16.3ą15.2%), 48 (-14.7ą13.2%) and 72 h (-8.6ą15.7%) post-ECC. The decrease in MVIC immediately post-ECC was correlated (P<0.05) with that at 24 (r=0.46), 48 (r=-0.52), and 72 h (r=0.47) post-ECC. Immediately post-ECC, RFD (e.g., 0-30-ms: -38.3ą31.4%), TF (-45.9ą22.4%), Mmax (-5.0ą16.8%), VA (-21.4ą16.5%) and SICI (-0.4ą13.8%) also decreased (P<0.05), while MEP at 10% MVIC increased (P<0.01) by 9.8ą23.2%. The decrease in the RFD immediately post-ECC was strongly correlated (P<0.01) with the changes in MVIC at 24 (r=0.60) and 48 h (r=0.63) post-ECC. The increase in MEP was strongly correlated (P<0.05) with changes in MVIC at 24 (r=-0.53) and 48 h (r=-0.54) post-ECC, but changes in TF were correlated with the change in MVIC at 48 h post-ECC only (r=0.46). No significant correlations (P>0.05) were evident between changes in VA (rs=0.04-0.15), SICI (r=0.01-0.12) and Mmax (rs =0.27-0.39) immediately post-ECC and MVIC strength at 24-72 h post-ECC. CONCLUSIONS: The results suggest that the magnitude of prolonged decrease in MVIC is reflected in the magnitude of changes in RFD and MEP immediately post-ECC. These parameters could be used to predict the occurrence of muscle damage immediately post-ECC. Since changes in VA, SICI and Mmax appear to reflect neuromuscular fatigue, they could be used to assess the extent of fatigue in the MVIC decrease immediately post-ECC.

Session Fatigue 2

F2-1: Enhanced availability of serotonin affects cortical silent period and perceptions of fatigue during prolonged submaximal isometric contraction

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BACKGROUND AND AIM: During fatiguing maximal effort contractions, intense serotonin (5-HT) release via the raphe-spinal pathway causes 5-HT to spill over from the motoneuronal somato-dendritic compartment to activate inhibitory 5-HT1A receptors on the axon initial segment. This spill over of 5-HT reduces motoneuronal output and is a mechanism of central fatigue. Although 5-HT release onto motoneurons is likely graded to the intensity of voluntary contraction, it is unknown if weak 5-HT release during fatiguing submaximal contractions also cause 5-HT spill over and exacerbates central fatigue. The purpose of this study was to assess the effect that enhanced availability of 5-HT has on the performance of sustained submaximal contractions. METHODS: Fifteen healthy individuals (22.3 ą 2.1 yr, 4 female) ingested the selective 5-HT reuptake inhibitor (SSRI) paroxetine in a double-blind, placebo-controlled, repeated-measures crossover design. Participants performed a low-intensity, isometric elbow flexion for 30 min at 15% of maximal voluntary contraction (MVC). Throughout the sustained submaximal contraction, brief MVCs were performed every 2 min and torque and EMG responses to transcranial magnetic stimulation (TMS) of the motor cortex, electrical stimulation of the brachial plexus, and motor point stimulation of the biceps brachii were obtained. After 30 min of sustained submaximal contraction, brief MVCs were performed so that stimulation responses could be assessed over a 10 min recovery period. Ratings of perceived fatigue were obtained throughout testing. RESULTS: Paroxetine did not influence elbow flexion torque or voluntary activation during brief MVCs performed throughout the sustained submaximal contraction. However, paroxetine increased the perception of fatigue ($P = 0.005$), and reduced the fatigue-induced lengthening of the biceps silent period elicited via TMS both during sustained submaximal contraction ($P = 0.003$) and during brief MVCs performed during sustained submaximal contraction ($P = 0.011$). Recovery from sustained submaximal contraction was similar for the placebo and paroxetine conditions. CONCLUSIONS: Motor performance was unaffected by paroxetine, which suggests that activation of 5-HT1A receptors on motoneurons was not increased by enhanced availability of 5-HT. We postulate that the level of voluntary drive was not sufficient to cause intense release of 5-HT from the raphe-spinal pathway onto motoneurons. However, perceived fatigue was greater and intracortical inhibitory activity was reduced following the enhancement of endogenous concentrations of 5-HT during sustained submaximal contraction. Thus, 5-HT may affect supraspinal processes associated with fatigue during low-intensity contractions without directly altering the voluntary motor pathway.

F2-2: Changes in muscle activation variability following dynamic elbow flexion exercise and relationships with muscle deoxygenation and swelling in young and old females

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BACKGROUND AND AIM: Old adults typically show more variability in motor patterns than young adults and, following fatiguing upper limb work, young and old adults have shown increased muscle activation variability, suggesting that the variability of motor strategies to prolong performance may change in old age. Old age and fatigue are also associated with altered physiology and structure of muscle, including altered muscle deoxygenation and swelling. These alterations may influence the adjustments in muscle activation variability, however this hypothesis has never been experimentally verified. Thus, we conducted an experimental study using a repetitive fatiguing task to determine if fatigue-induced deoxygenation and swelling were related to changes in muscle activation variability, and if these relationships differed by age. METHODS: Fifteen young female (23.3 ą 3.1 years) and ten old female adults (62.8 ą 6.9 years) completed repeated trials of an intermittent elbow flexion task using an isokinetic dynamometer. Each trial consisted of a 60-second bout of 60°/s concentric/eccentric repetitions at 20% maximal voluntary isometric contraction (MVIC), a 30-second rest, and a MVIC; trials were repeated until MVIC torque was < 70% of baseline. Anterior deltoid (AD), Biceps brachii (BB), and brachialis (BRA) activation was evaluated using surface electromyography and activation variability was quantified by the repetition-to-repetition coefficient of variation of root mean square values (CV). BB oxygenation was measured using near-infrared spectroscopy and BB and BRA muscle thicknesses (MTH) were measured using B-mode ultrasonography. A general estimating equation tested for Age*Trial*Muscle effects on CV. Spearman correlations analyses were conducted to test for relationships between First-to-Final changes in oxygenation (deoxygenation) and MTH (swelling), and the First-to-Final changes in CV in each age group. MAIN RESULTS: There were no effects of Age on CV, but BRA CV significantly decreased in the first half of the task (T*M: $p = 0.032$). In young females, there were moderate relationships ($\rho = 0.42$-0.69), $p < 0.05$) between changes in AD CV and in concentrations of deoxygenated and total hemoglobin, but no relationships between the changes in CV and in MTH ($p > 0.05$). In old females, there was a strong relationship ($\rho = 0.74$, $p = 0.021$) between changes in BB CV and in BRA MTH, but no relationships between the changes in CV and in muscle oxygenation. CONCLUSION: In contrast with previous studies of repetitive tasks (that mainly focused on the shoulder), BRA activation variability decreased with fatiguing elbow flexion exercise, suggesting that, despite some elbow flexor redundancy, fewer muscle recruitment strategies are used following fatigue development in tasks with limited degrees of freedom. Individual activation variability responses in young and old females related to different muscle responses, providing preliminary evidence that age may alter mechanisms that explain how variability in muscle recruitment develops.

F2-3: The impact of dynamic wrist flexor and extensor fatigue on hand tracking performance

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BACKGROUND AND AIM: The wrist flexor and extensor muscles play different functional roles when controlling wrist movement. The flexors can be considered task-dependent, while the extensors provide a greater stabilizing role for the wrist joint. However, minimal work has investigated wrist function when the wrist flexors or extensors are independently fatigued. Therefore, the purpose of this work was to examine how fatigue of the wrist flexors and extensors, using dynamic contractions, impacts strength and hand tracking performance. METHODS: Eighteen right hand dominant participants were recruited (10M, 8F). Participants placed their right forearm in a 3DoF wrist manipulandum (WristBot, Genoa, Italy) with their hand grasping the handle of the device. Interfaced with a virtual reality emulating a tracking task, the position of the handle was displayed as a blue circle on the screen. The tracking pattern was a 3:2 Lissajous curve, sized to ą45° of wrist flexion/extension and ą25° of radial/ulnar deviation. A yellow target moved around this curve at 9°/s as participants attempted to match the target. Following practice, 5 baseline traces were performed prior to fatigue. Participants then fatigued either their wrist flexors or extensors in a randomized order, with sessions separated by 7 days. For the fatigue protocol, participants placed their hand in a custom-built device which allowed for fatigue of either the wrist flexors or extensors. Participants performed 5 sets to failure with 45 seconds separating each set. Fatigue weight was set to produce 15-20 repetitions on the first set. Once fatigued, participants returned to the robot and performed 7 traces spread out from immediate post-fatigue (0 min) to 10 minutes post-fatigue. Maximal voluntary contractions (MVCs) of wrist flexion or extension were performed at 2, 6, and 10 minutes post-fatigue. Tracking error was assessed as the displacement of the handle from the target in both the x and y direction. Mean error was calculated across the entire trace. RESULTS: A significant decrease in force was observed at all time points following the fatiguing protocol (Pre: 146.1 ą 9.7N; 2 min: 114.4 ą 6.9N; 6 min: 122.0 ą 7.3N; 10 min: 124.4 ą 7.4N, $p < 0.05$). Tracking error significantly increased immediately following fatigue (Pre: 1.39 ą 0.05°; 0 min: 1.89 ą 0.14°, $p < 0.05$). Tracking error recovered quickly, returning to pre-fatigue error values by the 1-minute post-fatigue trace. CONCLUSIONS: These findings demonstrate that, although the wrist flexors and extensors serve different functional roles, fatiguing either muscle group affects hand tracking performance equally. The impact and recovery from dynamic fatigue does not differ between the wrist flexors and extensors regarding tracking error or maximal force output. Tracking performance decreased immediately following fatigue, however recovered rapidly and this may indicate a change in control strategies used to maintain performance.

Session Neuromuscular Imaging 1

I1-1: Exploring the electro-mechanical properties of fasciculations in amyotrophic lateral sclerosis

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BACKGROUND AND AIM: In amyotrophic lateral sclerosis (ALS), motor neurons become hyperexcitable and spontaneously discharge electrical impulses called fasciculations. They can be detected by two non-invasive methods, namely high-density surface electromyography (HDSEMG) and muscle ultrasonography (MUS), which offer practical advantages and provide greater patient tolerance over invasive needle EMG. Therefore, we chose to combine these two methods simultaneously to explore the electro-mechanical properties of fasciculations. We sought to identify a potential biomarker of disease. METHODS: Five ALS patients and six healthy subjects underwent six 50-second combined recordings from both the right biceps brachii and the right gastrocnemius medialis. Two novel analytical techniques (Surface Potential Quantification Engine and Gaussian mixture model) were used for HDSEMG and MUS data, respectively. We considered correlated fasciculations as those that produced an electrical peak on HDSEMG followed by a mechanical peak on MUS within 500 milliseconds. RESULTS: For 38% (215/564) of fasciculations detected by MUS across both groups, there was a corresponding fasciculation potential on HDSEMG. However, only 8% (215/2831) of fasciculation potentials detected by HDSEMG were also seen using MUS. The median depth of the 215 correlated fasciculations was 15.8 mm (inter-quartile range [IQR] = 9.5-23.5mm) compared to the median depth of 27.9 mm (IQR = 23.3-39.3mm) for the 349 fasciculations detected by MUS alone ($p < 0.01$). There was a non-linear, negative relationship between fasciculation potential amplitude on HDSEMG and the depth of fasciculation on MUS (Spearman's r = -0.395, $p < 0.01$, n = 215). There was a trend for greater electro-mechanical peak latencies in ALS patients (72ms, IQR = 55-272ms) compared to healthy subjects (64ms, IQR = 54-103ms; p = 0.087), although this failed to reach significance. CONCLUSIONS: We successfully demonstrated the practical feasibility of simultaneous recordings of HDSEMG and MUS. The correlation rates were lower than expected, which is partly due to the 2-dimensional nature of the MUS technique compared to 3-dimensional HDSEMG data collection. We demonstrated that HDSEMG detected fasciculations as deep as 35mm, highlighting its spatial sensitivity. Moreover, we detected a trend for increased electro-mechanical latencies in ALS patients, prompting further studies in a greater number of patients to determine its utility as a potential biomarker of disease.

I1-2: Verification of surface electromyographic activity of the oblique externus abdominis using ultrasound shear wave elastography

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The oblique externus abdominis (OE) is the most superficial muscle among the lateral anterior abdominal muscles. Surface electromyography (EMG) is used to measure muscle activation of the OE, but it is possible that EMG signals recorded by surface electrodes placed over the OE include the influence of adjacent muscles such as the oblique internus abdominis (OI). In contrast, ultrasound shear wave elastography provides an index of OE activity without the influence of adjacent muscles. Therefore, this study verified surface EMG activity of the OE using ultrasound shear wave elastography. Ten healthy male subjects performed right and left axial rotation of the trunk using a seated rotary torso machine. The upper body of the subject remained in a fixed position while the lower body rotated on a swivel. Isometric axial rotation was performed for 5 seconds against the weight corresponding to 25, 50, 75, and 100% maximal voluntary contractions (MVCs). Fiber orientation of the right OE was detected using B-mode ultrasonography, and surface electrodes were placed in parallel with the fiber orientation. Root mean square amplitudes of the EMG signals were calculated over 4 seconds during each axial rotation, and the amplitudes were normalized by the amplitude during right axial rotation at 100%MVC. Shear wave velocity, an index of muscle activation, of the right OE during the axial rotation at 25, 50, and 75%MVC was measured using ultrasound shear wave elastography. The transducer of the shear wave elastography was aligned in parallel with the OE fiber orientation. EMG amplitude during right and left axial rotation significantly increased from 25 to 75%MVC. The EMG amplitude at 25%MVC was not significantly different between right and left axial rotation, but the amplitudes at 50 and 75%MVC were significantly greater during right axial rotation compared with those during left axial rotation. The shear wave velocity during right axial rotation significantly increased from 25 to 75%MVC, but the velocity during left axial rotation did not significantly change. At each contraction intensity, the shear wave velocity during right axial rotation was significantly greater than that during the left axial rotation. Significant increases were observed in EMG amplitude and shear wave velocity with increasing contraction intensity during the right axial rotation and no significant change in shear wave velocity with increasing contraction intensity during left axial rotation; these findings support the finding established by biomechanical analysis that the OE influences contralateral axial rotation of the trunk in the transverse plane. A significant increase in EMG amplitude with increasing contraction intensity during left axial rotation may be attributed to muscle activation of the OI that acts on ipsilateral axial rotation of the trunk. From these findings, it is concluded that EMG signals recorded by surface electrodes placed over the OE includes the influence of the OI underlying the OE.

I1-3: Stress provides a lower-bound estimate of shear wave velocity in skeletal muscle

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Shear wave elastography can be used to characterize the mechanical properties of unstressed materials. This technique, which involves measuring shear wave propagation, has been used to study muscle during loaded and unloaded conditions. In many studies of contracting muscle, measurements of shear wave velocity (SWV) have been assumed to be directly related to the material properties of muscle, most commonly stiffness. Some have also used measures of SWV to estimate force since muscle stiffness and force covary during active contractions performed under normal conditions. However, few have considered the direct influence of muscle force on SWV, independent of the force-dependent changes in muscle stiffness, even though it is well known that force in a material influences shear wave propagation. We previously used an experimental manipulation to demonstrate that SWV is sensitive to changes in muscle stiffness that occur independently from changes in muscle force. Here we perform a complementary experiment to evaluate the influence of force on SWV. Our purpose was to determine how well changes in muscle force alone can explain measurements of SWV in passive and active muscles. Experiments were designed to test the null hypothesis that force alone could be used to predict SWV, comparing experimentally measured changes in SWV to predictions from a theoretical model of shear wave propagation. Data were collected from six isoflurane-anesthetized cats; three soleus muscles and three medial gastrocnemius muscles were tested. Muscle force was measured directly along with SWV, the latter using ultrasound elastography. Measurements were made across a

range passively and actively generated forces, obtained by varying muscle length and activation. Activation was controlled by stimulating the sciatic nerve. Muscles not being tested were denervated. Measured forces were normalized by physiological cross-sectional area, resulting in estimates of stress that could be compared across muscles. We found that the theoretical model of how stress influences SWV predicted our experimental results well for passively stretched muscles (Fig. 1). The errors for this model were not significantly different from zero (0.20 ą 0.22 m/s; mean ą 95% CI; p=0.08). In contrast, this same model significantly underpredicted the SWV in active muscles (2.72 ą 0.44 m/s; p~0). Results were consistent in the soleus and medial gastrocnemius muscles, suggesting our results generalize across muscles with different architectures and fiber types. These findings demonstrate that SWV is sensitive to changes in muscle stress and that a model of how stress influences SWV can be used to predict the SWV in passively stretched muscles. This same model provides a lower bound on the SWV in active muscle, presumably due to activation-dependent changes in muscle stiffness. Together, our results provide further clarity on the factors influencing shear wave propagation in muscle.

I1-4: Are SENIAM guidelines suitable for surface electromyography recordings of the semitendinosus muscle after harvest for anterior cruciate ligament reconstruction?

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BACKGROUND AND AIM: Anterior cruciate ligament (ACL) injuries are debilitating and increasingly frequent. Treatment typically involves surgical reconstruction of the ACL (ACLR) using the semitendinosus (ST) tendon. Despite a high regeneration rate of tendinous tissue, the ST muscle belly significantly shrinks and retracts. As SENIAM guidelines were developed for healthy individuals, we used a novel approach to investigate if the SENIAM suggested placement of surface electrodes for ST is suitable for ST-ACLR individuals. METHODS: Nine individuals (20-37 years; 33% males) who underwent unilateral ACLR using a ST tendon graft (9-18 months post-surgery) laid prone with their posterior thigh scanned bilaterally. A 60mm ultrasound transducer (L12-5N60-A2, ArtUS, Telemed) was used to visualize the ST muscle at 15° and 90° of knee flexion (0° = full extension) at rest and during maximal voluntary isometric contractions (MVC) performed on an isokinetic dynamometer (System 4 Pro, Biodex). Transverse plane ultrasound images were acquired at 50% of the distance between the ischial tuberosity and the medial tibial epicondyle (SENIAM guidelines for ST). Visibility of the ST muscle (i.e., if the muscle had retracted past the scan location) was noted and anatomical cross-sectional area (ACSA) was measured. ST muscle retraction was quantified at rest by measuring the distance from the muscle-tendon junction (visualized with ultrasound) to the popliteal crease with the hip and knee neutral. 2D axial proton density magnetic resonance images were acquired to verify ST tendon regeneration. Statistical comparison between limbs was made using a repeated-measures ANOVA. RESULTS: 67% of participants had tendon regeneration. Due to muscle retraction (5.8ą4.0cm), the ST muscle was not visible at rest in three participants at 15° and four at 90°. In three other participants at 90°, ST was visibly small at rest but further retracted during MVC (no longer visible). At rest, ST ACSA was 63% (mean of individual relative change values) smaller at 15° in the ACLR limb (healthy: 8.4ą2.3cm²; ACLR: 3.4ą3.5cm²; p<0.001), and 80% smaller at 90° (healthy: 4.7ą2.5cm²; ACLR: 1.1ą1.3cm²; p<0.001). During MVC, ST ACSA was 73%

smaller at 15° in the ACLR limb (healthy: 7.2ą2.4cm²; ACLR: 2.3ą2.5cm²; p<0.001), and 94% smaller at 90° (healthy: 2.7ą2.4cm²; ACLR: 0.3ą0.6cm²; p=0.006). CONCLUSION: The ST ACSA deficit was larger than previously reported for maximal ACSA¹, suggesting ST maximal ACSA shifts proximally after ACLR. At the scanned thigh location, ST is smaller (if not fully retracted) in the ACLR leg, while adjacent muscles are near their maximal size². Therefore, using SENIAM guidelines for the ST muscle after its harvest for ACLR are likely to expose surface electrode recordings to substantial amounts of cross-talk, if even recording from ST at all. REFERENCES: 1. Konrath J, et al. (2016). Am J Sports Med. 44, 2589-2598; 2. Kositsky A, et al. (2020). Ultrasound Med Biol. 46, 55-63.

Session Modelling and Signal Processing 1

M1-1: Motor unit tracking across different contraction levels in high-density surface electromyograms of tibialis anterior muscle

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BACKGROUND AND AIM: Due to its recent advances, decomposition of high density surface electromyograms (HDEMG) into contributions of individual motor units (MUs) is fast entering many neurophysiological studies [1]. Decomposition methods search for a weighted linear spatio-temporal combination of HDEMG recordings, so called MU filter, which, when applied to HDEMG recordings, directly estimates MU spike train. MU filters are typically identified during controlled muscle contractions (calibration phase) and, afterwards, applied to new HDEMG recordings (application phase), providing that the muscle geometry has not changed. Herein, we test the efficiency of such MU filter application to HDEMG recordings of different contraction levels of tibialis anterior muscle. METHODS: We used two arrays of 5 x 9 surface electrodes to record HDEMG signals from the tibialis anterior (TA) muscle of seven young males. We recorded 15 s long contractions at 50%, 60% and 70% of maximum voluntary contraction (MVC). We used Convolution Kernel Compensation (CKC) method [1] to identify MU filters from each individual contraction level. We then applied the identified MU filters to HDEMG recordings of other contraction levels in the same person. With true MU firings unknown, the following metrics were used for MU filter efficiency assessment: Pulse-to-Noise Ratio (PNR) [3] and median discharge rate (MDR). MU was classified as unidentified/not active, whenever MU filter identified spike train with PNR < 22 dB. The results are averaged across seven persons. RESULTS AND CONCLUSIONS: MU filters, estimated by CKC from HDEMG recordings of 50% MVC contraction identified 16.7 ą 6.4 MUs. When applied to 60% and 70% MVC contractions, these filters identified spike trains of 15.3 ą 5.6 MUs and 5.9 ą 3.4 MUs, respectively. A similar trend was noticed when applying MU filters from 60 % MVC contraction (16.4 ą 6.6 MUs) to 70% MVC contractions (9.1 ą 6.9 MUs). When applying MU filters from 70% MVC contraction (13.4 ą 5.4 MUs) to 60% and 50% MVC contraction, the number of identified MU spike trains decreased to 10.4 ą 6.3 and 7.9 ą 5.8, respectively, presumably also due to MU derecruitment. Mean PNR decreased in higher-than-calibration test conditions (from 32.1 ą 1.6 dB at

50% MVC calibration to 24 ą 1.1 dB at 70% MVC contraction) and also in lower-than-calibration contractions (from 31.5 ą 2 dB at 70% MVC caibration to 29.9 ą 2.8 dB in 50% MVC contraction). Mean MDR increased in higher-than-calibration conditions (from 15.7 ą 0.8 Hz at 50% MVC calibration to 23.6 ą 2.8 Hz at 70% MVC contraction) and decreased in lower-than-calibration conditions (from 22.4 ą 2.8 Hz at 70% MVC calibration to 13 ą 1.3 Hz in 50% MVC contraction). MU tracking across different contraction levels of TA muscle is feasible, but the quality of tracking is MU specific and needs to be carefully assessed. ACKNOWLEDGEMENT: This study was supported by the Slovenian Research Agency (projects J2-7357, J2-1731 and L7-9421 and Programme funding P2-0041). [1] A. Holobar and D. Farina. Blind source identification from the multichannel surface electromyogram.Physiol. measur., 35(7):R143, 2014. [2] A. Holobar and D. Zazula. Multichannel blind source separation using convolution kernel compensation.IEEE Trans. Sig. Proc., 55(9):4487-4496,2007. [3] A. Holobar, M. A. Minetto, and D. Farina. Accurate identifica-tion of motor unit discharge patterns from high-density surface emg and valida-tion with a novel signal-based performance metric.J. Neural Eng.,11(1):016008, 2014. [Figure 1 about here.] Figure 1. Representative examples of identified MU spike trains (blue signal) and MU firings (red circles). All the depicted spike trains were estimated by the same MU filter, which was identified at 70% MVC contraction and applied to different contraction levels of the same TA muscle. For clarity reasons only 1 s long epochs are depicted.

M1-2: On the Feasibility of Compound Muscle Action Potential Decomposition by Differential Evolution Algorithm

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BACKGROUND AND AIM: By supporting the non-invasive analysis of neural codes, identification of motor unit (MU) firings from high-density surface electromyograms (HDEMG) has gained considerable research interest in the last two decades [1]. In this study, we propose a new method for Compound Muscle Action Potential (CMAP) decomposition, based on improved differential evolution (DE) algorithm [2]. The proposed method requires knowledge of motor unit action potentials (MUAP), which are then used to decompose CMAP into contributions of individual MUs. The MUAPs can be estimated from voluntary contractions by Convolution Kernel Compensation (CKC) algorithm [5]. METHODS: We have used synthetic HDEMG signals [6] with different numbers of MUs contributing to CMAPs and different MU synchronization levels. Simulated array of electrodes comprised 10 Õ 9 circular electrodes. Three different MU activation levels were simulated, resulting in 136, 168 and 200 active MUs per stimulus. MU firings were normally distributed around the common time moment with standard deviation set to 13 ms, 7 ms, 3 ms, 1 ms and 0 ms, respectively. This resulted in 10%, 20%, 40%, 80% and 100% synchronization of MU firings. Five different simulation runs were conducted per each activation and synchronization level pair. The proposed method for CMAP decomposition is based on improved jDErpo algorithm [2], which we have modified to binary form, as proposed in [3]. To decrease its computational complexity, the proposed method was tested on 16 preselected HDEMG channels that were evenly distributed across the entire simulated electrode array. RESULTS: When averaged across all the MU synchronization levels, the proposed method accurately identified firings of 3.6 ą 3.0, 3.2 ą 2.0 and 3.6 ą 2.4 MUs in CMAPs with 136, 168 and 200 active MUs, respectively (Figure 1). The number of identified

MUs increased significantly with the MU synchronization level and was not significantly affected by the MU activation level. CONCLUSIONS: We demonstrated the ability of CMAP decomposition on synthetic HDEMG signals using modified jDErpo algorithm [2][3], especially at extremely high MU synchronization levels. ACKNOWLEDGEMENT: This work was supported by the Slovenian Research Agency (projects J2-1731 and L7-9421 and Programme funding P2-0041) [1] A Holobar, D Farina. Blind source identification from the multichannel surface electromyogram. Physiological Measurement, 35(7): R143-R165, 2014 [2] J. Brest, A. Zamuda, I. Fister, and B. Boskovic. Some improvements of the self-adaptive jDE algorithm. In2014 IEEE Symposium on Differential Evolution (SDE), pages 1-8, 2014 [3] Tao Gong, Andrew L. Tuson. Differential evolution for binary encoding. In Ashraf Saad, Keshav Dahal, Muhammad Sarfraz and Rajkumar Roy, editors, SoftComputing in Industrial Applications, pages 251-262, Berlin, Heidelberg, 2007. [4] A Holobar, V Glaser, J A Gallego, J L Dideriksen, D Farina. Non-invasive characterization of motor unit behaviour in pathological tremor. Journal of Neural Engineering, 9(5):056011, 2012. [5] A. Holobar and D. Zazula. Multichannel blind source separation using convolution kernel compensation. IEEE Transactions on Signal Processing, 55(9):4487-4496, 2007. [6] Farina D, Mesin L, Martina S, Merletti R 2004 A surface EMG generation model with multilayer cylindrical description of the volume conductor IEEE Trans Biomed Eng 51 415-426. (figure 1 here) Figure 1. No. of MUs (mean ą SD) with accurately identified MU firings (tolerance of 0.5 ms), averaged across all the simulation runs with 136, 168 and 200 active MUs.

M1-3: Automatic assessment of individual motor unit firing identification accuracy from high-density electromyograms

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BACKGROUND AND AIM: The studies that build on neural codes obtained from high-density surface electromyograms (HDsEMG) have been growing in number over the last few years. All of them require accurate identification of individual motor unit (MU) firings. To the best of our knowledge, the existing methods estimate the accuracy of the entire MU spike train estimation, whereas no solution for accuracy assessment of individual MU firing has been presented up to now. In this study, we present and test a new algorithm for automatic identification of individual MU firing accuracy from HDsEMG [2]. METHODS: Our proposed algorithm is based on Pulse-to-Noise Ratio (PNR) metric [1] and can be applied to every MU that is identified by Convolution Kernel Compensation (CKC) method [1]. P highest spikes from MU spike train are selected as PNR witnesses and all the remaining potential spikes are put into testing dataset. In the second step, which is repeated for each test spike in the testing dataset, a new MU filter is calculated from P witnesses and the test spike and used to re-estimate the spike train of the same MU. PNR is calculated on P witnesses in this new spike train. This procedure is repeated across all the test spikes of a given MU, yielding several PNR values. In the last step, segmentation adapted for bimodal distribution is applied to the calculated PNR values, yielding the PNR threshold. All the test spikes with corresponding PNR values above this threshold are classified as true positives (TP), whereas all the other spikes are classified as false positives (FP). The algorithm was tested on 20 s long experimental signals, acquired concurrently with surface and intramuscular techniques from biceps brachii muscle of five healthy men. Obtained signals were decomposed and MUs jointly identified in surface and intramuscular EMG have been used for evaluation of our algorithm. Results of intramuscular EMG decomposition were used as a reference, with the identification tolerance set to 0.5 ms. RESULTS: In total, 19 MUs with average number of 21.3 ą 4.6 FPs were used for evaluation. With number of witnesses set to P=40, the number of FPs among witnesses was 0.3 ą 0.5. After the use of the proposed algorithm, the number of FPs decreased significantly (Friedman test with Bonferroni correction, $p < 0.05$) to 4.4 ą 3.7 (Figure 1). CONCLUSIONS: We presented a new algorithm which can distinguish between TP and FP spikes in the CKC-identified MU spike trains. In our study, the average precision of CKC-based MU identification increased from 91.8 ą 2.7 % to 96.9 ą 2.4 % when the individual spike assessment algorithm has been employed. The presented algorithm has the potential to automatically improve the HDsEMG decomposition results. ACKNOWLEDGEMENT: This study was supported by the Slovenian Research Agency (projects J2-7357, J2-1731 and L7-9421 and Programme funding P2-0041). REFERENCES: [1] A. Holobar, M. A. Minetto, and D. Farina, "Accurate identification of motor unit discharge patterns from high-density surface EMG and validation with a novel signal-based performance metric," J Neural Eng., vol. 11, no. 1, p. 016008, Feb. 2014. [2] F. Urh and A. Holobar, "Automatic identification of individual motor unit firing accuracy from high-density surface electromyograms," IEEE Trans. Neural Syst. Rehabil. Eng., doi: 10.1109/TNSRE.2019.2961680. (Figure_1.tif here) Figure 1. The left panel depicts mean and standard deviation of PNR values of TP and FP spikes, and the right panel their distribution with the fitted Gaussian curve. In our study, decomposition of intramuscular EMG signals enabled discrimination and different coloring of PNR values that are contributed by TP and FP spikes, respectively. The PNR values from TP and FP spikes form a clear bimodal distribution; * - statistically significant difference (Friedman test with Bonferroni correction, $p < 0.05$).

M1-4: On the motor unit pool identification from high-density surface electromyograms of tibialis anterior muscle

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BACKGROUND AND AIM: Motor unit (MU) identification from high-density surface electromyograms (HDEMG) offers a valuable insight into neural codes of the peripheral neural system (PNS) and, thus, into control strategies of corresponding alpha motor neuron pool. With several tens of identified MUs, the population coding typically used for analysis of central nervous system is fast entering the field of PNS studies, revealing new insights about MU synchronization and muscle synergies, for example. Although in ideal conditions up to 70 concurrently active MUs can be identified from a single HDEMG recording, the typical number of MUs identified from a single contraction ranges between 10 and 30. There is currently no consensus on the total number of MUs that can be identified and characterized from HDEMG signals of different muscles, when these HDEMG signals are recorded across different contraction levels. In this study, we performed such analysis for tibialis anterior (TA) muscle in young subjects. METHODS: HDEMG has been recorded from TA of five young males (age 32 ą 4 years, height 175 ą 4 m, weight 75 ą 10 kg), using two arrays of 5Õ9 electrodes (LISiN, Politecnico di Torino, Italy, 1 mm in diameter, inter-electrode distance of 5 mm). The 15 s long constant force contractions at 10 %, 20 %, 30 %, 50 %, 60 % and 70 % of maximum voluntary contraction (MVC) were recorded (each contraction level was recorded twice). Convolution Kernel Compensation (CKC)

method [1] was used to decompose the HDEMG signals into MU spike trains and all the MUs with Pulse-to-Noise Ratio (PNR) < 28 dB or with less than 50 identified MU firings were discarded. The remaining MU spike trains were used in spike triggered averaging (SPA) of HDEMG signals to calculate high-density representations of MU action potentials (MUAPs). MUAPs of different MUs were pairwise compared by calculating the Normalized Root Mean Square Error (NRMSE) and Pearson's Correlation Coefficient (CC) across all HDEMG channels. In this comparison, the MUAPs were declared to belong to the same MU whenever CC > 0.7 and NRMSE < 0.6. RESULTS: On average, 58 ą 18 MUs (range 44 - 80 MUs) have been identified per muscle. 62 ą 9 % of them (36 ą 13 MUs) have been identified from ≤ 30 % MVC contraction levels. High contraction levels (≥50 % MVC) and low contraction levels (≤ 30 % MVC) shared only 13 ą 11 % of MUs (8 ą 6 MUs). Peak-to-peak amplitude of the smallest detected MUAP per person accounted for 6.7 ą 2.9 % (range 2.6 - 9.0 %) of the largest peak-to-peak MAUP amplitude (Figure 1). CONCLUSIONS: We demonstrated that relatively high number of MUs can be identified from HDEMG signals of TA muscle, when several contraction levels are analysed. High threshold MUs represented relatively large portion (about 50 %) of MUs identified at high contraction levels. ACKNOWLEDGEMENT: This study was supported by the Slovenian Research Agency (projects J2-7357, J2-1731 and L7-9421 and Programme funding P2-0041). REFERENCES [1] A. Holobar and D. Zazula. Multichannel blind source separation using convolution kernel compensation. IEEE Transactions on Signal Processing, 55(9):4487-4496,2007. [2] A. Holobar, M. A. Minetto, and D. Farina, "Accurate identification of motor unit discharge patterns from high-density surface EMG and validation with a novel signal-based performance metric," J Neural Eng., vol. 11, no. 1, p. 016008, Feb. 2014. Figure 1 about here Figure 1. Examples of surface MUAPs from TA muscle in a subject with 80 detected MUs. MUAPs are depicted in single-differential mode (column-wise). MUs are sorted by peak-to-peak amplitude.

M1-5: A proposed pre-processing framework for facial surface electromyography

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BACKGROUND: Facial surface electromyography (fsEMG) has the potential for use in many clinical applications. However, its use is often limited as it suffers from poor signal quality. The poor quality of fsEMG can be attributed to the complex facial musculature and the fact that facial electromyographic signals have lower power than other skeletal muscular activations. Hence, fsEMG can easily be contaminated with noise generated by the recording equipment and/or surrounding factors. METHOD: To address this noise contamination issue, we have developed a multi-component framework for the pre-processing of fsEMG to improve the quality of the signals. The system incorporates an adaptive filter to remove baseline noise and the Hampel filter, a decision-based median filter, to remove outliers in the data. Experiments were conducted to record fsEMG from the corrugator supercilii muscle of volunteer participants with the data used to validate the proposed method. RESULTS: The baseline noise was reduced effectively using adaptive noise cancellation and there was a decrease in SNR values suggesting signal quality has increased. Hample filter has removed the outliers and a boxplot representation of pre and post filtering shows excellent results. Finally, a band pass filter of 30-300 Hz was used to remove any residual noises. CONCLUSION: Our study reveals that recording using pre-processing methods similar to ones reported in the literature is not reliable and hence limits the potential applications. To overcome these problems, we have developed a framework for the pre-processing of the signal such that it can be used by researchers working in a variety of different application areas. We have considered all of the most common noise sources that have previously been reported in literature and identified the most suitable processing methods for each. There are a number of potential clinical, and media related applications of fsEMG, many of which have not yet been explored due problems with reliability and the poor quality of the signal. The significance of this study is in the provision of a framework to improve the signal quality. This can potentially lead to new applications of the signals and open new research directions.

M1-6: Why and how to correct the Butterworth filter cut-off frequency for multiple passes.

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The Butterworth filter is designed to reduce power of unwanted frequencies with negligible effect on the power of wanted frequencies. Because of this flat frequency response in the passband filter characteristics, the Butterworth filter is a popular choice of filter and the most common filter used in human movement related research. The main drawback of the Butterworth filter is that the filter creates time delays or phase lags that are not consistent across the frequency range after the data is passed through the filter. Therefore, a simple shift of the filtered data in time would not suffice as a correction. To compensate for these delays, it is common to pass the data through the filter again but in reverse, also referred to as dual-pass zero-lag or zero-phase shift filtering. However, because the data is filtered twice (once in each direction), the selectivity (order) of the filter changes and additional power is removed from the signal. With each filter pass, the cut-off frequency (the frequency at which the amplitude of the data is reduced to ~70.7% or -3dB) is pushed towards lower or higher frequencies, depending if the filter is designed to filter out high (low-pass filter) or low (high-pass filter) frequencies, respectively. Therefore, the cut-off frequency is shifted away from the originally intended value and the filter order doubles with each filter pass. A correction for the cut-off frequency is required to compensate for multiple filter passes to keep the original intended cut-off frequency. Winter has described a correction factor in his book; Biomechanics and Motor Control of Human Movement (p69, 4th ed.), also referred to as the 'Winter Correction'. However, the Winter correction is specific for second order Butterworth filter designs and is frequently incorrectly applied, resulting in unwanted changes to the original filter design. In some cases, either not applying or erroneous application of the Winter correction may lead to different findings and lesser ability to reproduce other findings due to unintentionally incorrect reports of the actual filter design used. An example of incorrect use of the Winter correction is that the correction factor is applied directly to the cut-off frequency, instead of the angular cut-off frequency. This will lead to an erroneous correction of the cut-off frequency in which the amplitude of the error will depend on the cut-off frequency number, with higher cut-off frequencies resulting in larger errors. Another example is that the cut-off frequency will be corrected to the wrong direction when applying the Winter correction to a high-pass filter design as this method is specific for low-pass filter designs. In this case, the inverse of the Winter correction should be applied. This presentation will provide information on the technical background of Butterworth filter design, how to correct for multiple filter passes for different filter orders and how to double check the impact of bi-directional filtering on the intended filter design (cut-off frequency and filter order). In addition, suggestions are provided on how to report these in the methods section of a paper.

Session Motor Control 1

MC1-1: Effect of a dynamic isokinetic fatiguing task on the spatial distribution of erector spinae muscle activity in individuals with low back pain

Michail Arvanitidis[1], Nikolaos Bikinis[1], Stylianos Petrakis[1], Afroditi Gkioka[1], Dimitrios Tsimpolis[1], Deborah Falla[1], Eduardo Martinez-Valdes[1]
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BACKGROUND AND AIM: Muscle fatigue leads to a decline in a muscles' ability to generate force or power and thus has an important effect on motor output. In the presence of low back pain (LBP), a variety of neuromuscular deficits are commonly observed, including increased trunk muscle fatigability. However, this has mostly been measured as decreased time to task failure during non-functional tasks, typically isometric contractions. Our aim was to investigate the effect of muscle fatigue on the spatial distribution of erector spinae muscle activity and peak torque output in individuals with and without chronic LBP, during a dynamic isokinetic task performed until task failure. METHODS: Seated in an isokinetic dynamometer, 12 individuals with chronic LBP and 11 asymptomatic controls, performed maximal concentric trunk flexion-extension contractions continuously at 60š/s until volitional exhaustion. Electromyographic signals were acquired from the lumbar erector spinae muscle of all participants, using a high-density electromyography (HDEMG) grid of 64 surface electrodes. The root mean square (RMS) and mean power spectral frequency (MNF) were determined as an average for all electrode pairs. Additionally, the barycentre of the distribution of the HDEMG amplitude was calculated to assess changes in erector spinae spatial activation. Peak torque signals were recorded with the isokinetic dynamometer (System 3 Pro, Biodex Medical Systems, New York). RESULTS: The magnitude of muscle activation increased similarly during the fatiguing task for both groups (P=0.376). Likewise, the MNF decreased similarly during the fatiguing task for both groups (P=0.154). Both groups, performed a similar number of repetitions (P=0.376). Nevertheless, the extension and flexion peak torque exerted by the individuals with LBP was significantly lower (P=0.047 and P=0.046 respectively) and a significantly lower rate of perceived exertion was observed in this group (P=0.026). The spatial distribution of erector spinae muscle activity was shifted cranially in the LBP group throughout the task (P=0.045), while the controls showed a more homogenous distribution of muscle activity. CONCLUSIONS: This study provides new insights into the behaviour of the lumbar erector spinae muscle in the presence of muscle fatigue in people with LBP. More specifically, the cranial shift of the barycentre observed in the LBP group throughout the task suggest an inefficient recruitment of the erector spinae, which could possibly play a significant role in the persistence of LBP symptoms. HDEMG feedback could be considered in the future as an aid to optimise the recruitment strategy of the lumbar erector spinae muscle in individuals with LBP.

MC1-2: Stepping Responses and Dynamic Postural Stability Measures for Reactive Balance for Individuals with Incomplete Spinal Cord Injury

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Introduction Individuals with incomplete spinal cord injury (iSCI) experience impairment of the lower-limb sensorimotor functions. These individuals often show compromised reactive stepping balance, resulting in increased risk of falls. The purpose of this study was to compare how foot placement could be affected following iSCI during a reactive stepping task that simulated forward fall. We hypothesized that when experiencing a forward fall, individuals with iSCI cannot make adequate step(s) to stabilize the body. Method Twenty-seven healthy able-bodied (AB) individuals (42.3 ą 18.6 yr; 11 males and 16 females) and fifteen individuals with iSCI (56.1 ą 16.1 yr; 4 males and 11 females) participated in this study. Participants performed ten trials of the lean-and-release test, where the participant leaned forward while a tether supported 8-12% of the body weight. The tether was released randomly, simulating a forward fall which elicited reactive stepping. Kinematic and kinetic data as well as leg electromyography were recorded using a motion capture system, force platform and surface electrodes, respectively. Multiple measures of reactive strategies, including stepping strategies (i.e. single-step response, multiple-step response or required assistance), foot-off time (i.e. time taken to lift the foot from release), swing duration and step length, as well as the measure of dynamic postural stability (i.e., margin-of-stability (MOS) at 0.1 seconds after foot-contact) were calculated and compared across participant groups. These measures were used to characterize the stepping responses and estimate the theoretically appropriate foot placement during the reactive balance tasks. Results and discussion AB individuals predominantly utilized a single-step response to stabilize the body (single-step: 61.3% of trials; multiple-step: 38.7% of trials), while individuals with iSCI showed more multiple-step responses and falls compared to AB individuals (single-step: 2.12% of trials; multiple-step: 87.2% of trials; required assistance: 10.6% of trials). Group averages for the foot-off time (AB: 0.407ą0.110s and iSCI: 0.419ą0.073s; p=0.717), swing duration (AB: 0.154ą0.047s and iSCI: 0.162ą0.037s; p=0.563) and step length (AB: 0.332ą0.127m and iSCI: 0.344ą0.092m; p=0.749) did not show significant difference between participant groups. For individuals with iSCI, the MOS after the foot contact was significantly smaller than AB individuals (AB: 0.081ą0.074m and iSCI: 0.024ą0.100m; p=0.042), indicating that foot placement in response to a forward fall may not adequately stop the center-of-mass from moving forward. These measures of stepping responses and dynamic postural stability provide further insights towards how reactive stepping balance could be affected following iSCI in terms of foot placement. This work can contribute to better understanding the dynamic postural balance and postural control for individuals with iSCI.

MC1-3: Adaptations of motoneuron properties following 5-weeks of trans-spinal direct current stimulation

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BACKGROUND AND AIM: Trans-spinal direct current stimulation (tsDCS) mimics the physiological polarization processes which occur within the spinal networks. tsDCS does not evoke action potentials in neurons, but puts them in a state of subthreshold depolarization or hyperpolarization, depending on a polarity of applied current. It has recently been introduced as a promising neuromodulatory technique used for rehabilitation of patients with neurological disorders or as an addition to physical training. However, mechanisms of neuronal interactions in response to polarization are not fully understood. In our previous research we have shown that membrane properties and firing characteristics of motoneurons can be altered immediately after tsDCS application, and that these changes persist up to 60 minutes after the offset of polarization. The aim of this study was to determine whether tsDCS applied repeatedly for a longer period could evoke permanent adaptive changes in motoneurons. METHODS: The study was performed on 18 adult male Wistar rats under general anesthesia, which were randomly assigned to Anodal (n=6), Cathodal (n=6) and Sham/Control (n=6) groups. Transcutaneous spinal DCS of 0.5 mA intensity was applied under isolflurane anesthesia through an electrode located above the dorsal surface of the 1st lumbar vertebra, with a reference electrode located ventrally. Sessions of anodal or cathodal polarization lasted 15 minutes, and were repeated 5 days a week, for 5 weeks. The intracellular recordings were made from antidromically identified motoneurons innervating hind limb muscles to measure basic membrane and threshold properties, and to investigate rhythmic firing characteristics. One-way analysis of variance (ANOVA) was used for statistical comparisons between the groups. RESULTS: Recordings from 124 motoneurons were collected (41 in the Sham/Control, 40 in the Anodal and 43 in the Cathodal groups). In comparison to the mean control values, 5 weeks of anodal tsDCS resulted in the significantly increased mean input resistance, the hyperpolarized voltage threshold, the higher maximum steady-state firing (SSF) frequency, and the increased slope of the SSF frequency-current relationship. On the other hand, no significant adaptive changes were observed in motoneurons following cathodal tsDCS. CONCLUSIONS: The study demonstrated that chronic, repetitive application of tsDCS induced polarity-dependent adaptations of motoneuron properties. Anodal tsDCS modified threshold and firing properties of motoneurons towards facilitation of their activity. The findings may help to explain the influence of tsDCS on muscle performance and thus provide a basis for the potential implications of tsDCS interventions for sport or/and therapeutic purposes. Supported by the National Science Center grant No 2017/25/B/NZ7/00373.

MC1-4: Population motor unit activity during mechanically evoked upper limb reflexes

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BACKGROUND AND AIM: Feedback corrections to mechanical perturbation of our limbs or body are critical for purposeful movement and have been extensively investigated for decades. A common limitation of this work is that it examines the compound electrical activity (net EMG) of a muscle rather

than the isolated action potentials of its motor units (MU). Here we describe population MU activity of two upper limb muscles in response to mechanical perturbations. METHODS: Six individuals (23-47 yr) had their right arm encased by a robotic exoskeleton and high-density surface EMG array electrodes placed over an elbow flexor (brachioradialis) and elbow extensor (triceps lateral). Subjects maintained their hand within a small target against a constant flexion or extension torque at the elbow followed by a randomly timed pulse of elbow torque (100ms) which stretched or shortened the contracting muscle. Six blocks of 20 trials were collected. Offline, the EMG signals were analyzed in two ways: 1) the net EMG was calculated for each channel by traditional rectification and smoothing, then averaged across the array, and 2) the discharge times of active single motor units were decomposed using a semi-automated blind source separation decomposition algorithm (Negro et al. 2016). Separate peristimulus time histograms (PSTH) were constructed for the net EMG and MU discharge times by aligning either the conditioned EMG or the spike occurrence to the onset of the perturbation. Peristimulus frequencygrams (PSF) were constructed by aligning the instantaneous discharge frequency to the onset of the perturbation. RESULTS: The PSTH profiles derived from both the net EMG and the MU discharge times reveal similar trends which are classically observed with upper limb reflexes, namely a series of bursts corresponding to the short-latency reflex (SLR; 20-50ms) and long-latency reflex (LLR; 50-100 ms). Neither the net EMG nor MU derived PSTHs show a significant difference in magnitude between the SLR and LLR (both $p>0.05$). In contrast, the PSF reveals a different organization between the two reflexes - minimal change in discharge frequency in the SLR, and a large increase in discharge frequency during the LLR ($p<0.001$). CONCLUSIONS: Because the discharge frequency (PSF) more accurately reflects the membrane potential of the spinal motoneuron as compared to the discharge probability (PSTH), these data provide new information about the organization of neural drive to human spinal motoneurons. The close correspondence between net EMG and individual MU derived PSTH profiles provides evidence the MU decomposition may accurately capture the motor pool dynamics and that the net EMG reflex response can largely be explained by changes in the discharge rate of active motor units. The dispirit findings between the PSTH and PSF approaches suggests relatively complex neural drive may underlie the SLR whereas the LLR can largely be described as a single excitatory event.

MC1-5: Quantifying Spasticity during Voluntary Movements

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BACKGROUND AND AIM Spasticity leads to serious impairments in the execution of voluntary movements. According to Lance spasticity is characterized by a velocity-dependent increase in tonic stretch reflexes and does not include impaired voluntary movement and an abnormal posture. Therefore, sEMG is commonly used to investigate the muscles response to stretch in the presents of spasticity. However, these approaches do not take into account voluntary movements and the transfer of their results to everyday activities is often problematic. Other attempts, like the extraction of sEMG primitive synergies, aim to evaluate muscular coordination of patients suffering from disorders accompanied by spasticity. These attempts don't distinguish between spasticity and voluntary muscular activation needed to compensate weakness. Although the assessment of spasticity is important for clinical management, it still lacks an objective assessment methods quantifying the level of spasticity during voluntary movements. METHOD To overcome the limitations of existing methods sEMG envelope is measured synchronously with angle and angular velocity during voluntary movements. In order to achieve comparability joint angles are separated into intervals with a width of 20° and angular velocities into intervals with a width of 10°/s. Afterwards, sEMG envelopes are categorized with respect to joint angle and angular velocity [von Werder 2016]. Within each joint angle interval, the relationship between sEMG envelope and angular velocity is analysed. During eccentric contraction phases, an increase in the sEMG envelope with increasing velocity is considered as a sign of spasticity, while the gradient of the increase is used as a measure of the amount of spasticity. EXPERIMENTAL VALIDATION Voluntarily performed elbow flexion / extension movements of 15 healthy subjects and 7 patients with impaired upper limb function due to spasticity have been analysed. Spastic impairment was clinically assessed by the Wolf Motor Function Test (WMFT). Elbow motion has been executed at different velocities and with constant torque over the full range of motion. SEMG was recorded from biceps, brachioradialis and triceps. Elbow angle and elbow angle velocity were determined using a VICON motion analysis system. RESULTS In all healthy subjects biceps sEMG envelope decreased with increasing angular velocity during eccentric contraction phases [Figure 1, green dot]. This is in accordance to the force-velocity relationship knowen from biomechanics. This is in contrast to patients in which a voluntarily performed extension of the elbow leads to an increasing biceps sEMG envelope with increasing movement velocity [Figure 1, red dots]. In addition, a decreased WMFT score, which reflects a greater impairment due to spasticity, was associated with a higher gradient of this increase. CONCLUSION Experimental validation supports the hypothesis that during eccentric contraction, a positive relationship between sEMG envelope and movement velocity can be considered a sign of spasticity, while the gradient of this increase reflects the amount of spasticity. In this way quantification of spasticity occurring during voluntary performed movements becomes possible.

Session Motor Control 2

MC2-1: Effect of visual-motor illusion on functional brain connectivity during motor imagery

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Background and aim Visual-motor illusion (VMI) is a novel method that produces kinesthetic perception through observation of a person's physical exercise on a computer screen. VMI increases the excitability of the primary motor area (M1). VMI has been shown to activate the premotor cortex (PMC) and the parietal area (Pa). It has been reported that the illusion activates brain areas common to motor imagery. From this, we hypothesized that inducing VMI will affect the motor imagery ability as well as functional brain connectivity during motor imagery. Therefore, the purpose of this study was to verify whether VMI changes the motor imagery ability and brain functional connectivity during motor imagery. Methods The subjects were 13 healthy adults (mean age: 24.0 ą 4.2 years). The illusion condition and control condition were each conducted for 20 minutes. The illusion condition was induced by subjects observing finger movements made by themselves in a video. The control condition used the same video as the illusion condition. The position of the upper limb was such that no illusion occurred. Before and after each condition, functional brain connectivity during motor imagery and vividness of the motor imagery (visual analogue scale: VAS) were measured; after each condition, the degree of kinesthetic illusion and body ownership were measured using a 7-likert scale. Brain functional connectivity during motor imagery was measured via oxygenated hemoglobin (oxy-Hb) using functional near-infrared spectroscopy. We measured 40 channels in total. Motor imagery was performed 5 sets using a block design (rest 5 seconds -motor imagery 10 seconds -rest 5 seconds). The region of interest (ROI) was frontal-parietal regions. In analyses, band-pass filters were applied to the oxy-Hb and the correlation coefficient was calculated between each channel. Fisher's z-transform was performed. Bonferroni-adjusted paired t-tests were performed to identify changes in z-transformed connectivity in each pair of channels in the before and after each condition. We used a paired t-test that evaluated the degree of kinesthetic illusion and the degree of body ownership. The VAS evaluated using a variance analysis of two factors. Results Our results indicated that the degree of kinesthetic illusion and body ownership were significantly higher under the illusion condition ($p < 0.05$). The VAS was significantly higher under the illusion condition ($p < 0.05$). The functional brain connectivity between the left PMC and the left somatosensory area (S1), and between the left and right PMC and the left Pa increased significantly during motor imagery, before and after the illusion condition. After the illusion condition, compared with the control condition, functional brain connectivity changed between the left Dorsolateral prefrontal cortex and left PMC, left frontal eye field and left Pa, left and right PMC, left S1 and left Pa. These were areas related to VMI and motor execution. Conclusions In conclusion, the VMI changes functional brain connectivity during motor imagery.

MC2-2: Characterisation of neuromuscular adaptation in Backward vs Forward split-belt treadmill walking

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BACKGROUND AND AIM: The split-belt treadmill paradigm is widely used to investigate motor adaptation drivers during locomotion. Previously, it was shown that adaptations between backward and forward walking are not transferable (Choi and Bastian, 2007). In this study, we aim to characterize the changes in the muscular activation appearing during locomotor adaptations in both walking directions. METHODS: Six healthy subjects were asked to perform forward and backward walking on a split-belt treadmill. During the experiment data from 16 EMGs and force plates were collected. Participants performed 2 minutes of baseline walking with both belts set at a speed of 0.4 m/s followed by 10 minutes of the right belt running at 0.8 m/s, and a final 5 minutes of belts tied at 0.4 m/s. The EMG envelopes were extracted for the first, middle and last 10 strides of all the three phases. The amount of muscular activity in stance and swing was calculated, for each muscles, by integrating the envelope over the duration of the gait cycle. The delay between late baseline and other phases was calculated using cross-correlation. RESULTS: For the forward condition, all the muscles generating torques below the hip level showed an initial boost of the activation that faded in both the adaptation and post-adaptation phases. The main observed change was an increase in the use of the plantar-flexors on the perturbed side in stance, likely to facilitate a greater push-off. These muscles also activated earlier by about 10% coinciding with a shorter stance phase. The activation of the knee extensors and the tibialis anterior

increased at the beginning of adaptation in stance on the left side to stabilise the knee. The hip flexors contralateral to the perturbation had an additional boost of activation during the swing phase. In the backward adaptation, the changes for the muscles controlling the ankle appeared opposite. The main change of muscular activity on the perturbed side occurred for the tibialis anterior that generated unusual additional activation during the stance phase throughout the whole adaptation process, presumably to stabilize the knee, decelerate the progression of the COM or to prepare for the quicker push-off, that is facilitated by an additional peak in the activity of the gastrocnemius muscle. Contrary to the forward condition, plantar-flexors during backward increased their activation at the beginning of adaptation on the unperturbed side and faded by the end of adaptation. Between the muscles not acting on the ankle joint only the biceps femoris presented an initial increase of activity on both sides during adaptation and post adaptation phases. The activation patterns showed an anticipation of less than 5% on the perturbed side with no temporal changes on the other side. CONCLUSIONS: The muscular changes for the forward and backward adaptation need to facilitate different control strategies on the ankle joint level to increase step symmetry. The backward adaptation showed more side and location-specific changes. The difference in the adaptation strategies at the muscular level explains the lack of transition of adaptation between backward and forward walking.

MC2-3: Modularity in the control of prosthetic gait: low-dimensional description of the kinematics.

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INTRODUCTION: Amputation of a lower limb implies a re-organization in the strategies used to reach a stable walking pattern. The planar covariation law of elevation angles is a well-defined low-dimensional description of the kinematics of movement; according to this law, thigh, shank and foot elevation angle co-vary on a plane, defining a typical gait loop. While covariation of the elevation angles has been studied before, also in amputees [1], a robust biomechanical interpretation of the outcomes of its related analysis is still missing. In addition, evidence has been given that, at the neuromuscular level, the spatial composition of the modular structure is equivalent between amputees and control subjects [2]. In this work, we aimed to build a low-dimensional description of the kinematics of prosthetic gait that can be put in a direct relationship with the modular description of muscle activity. MATERIALS AND METHODS: 14 subjects with unilateral trans-femoral amputation, wearing a micro-controlled knee prosthesis (50 ą 14 y.o.) and a control population of 12 healthy subjects (53 ą 8 y.o.) participated in the study. Each subject performed 10 walking trials along a 9m long walkway with a self-selected comfortable speed (1.2 ą 0.1 m/s for controls CSS and 0.9 ą 0.2 m/s for amputees TF). Control subjects also performed the same task with a slower speed (0.9 ą 0.1 m/s, CSL). Kinematics of movement has been recorded using a motion capture system (BTS SMART DX6000) to extract elevation angles of thigh, shank and foot. Planar covariation law of elevation angles has been studied using PCA [3]. In order to assess the equivalence of the covariance plane in the three groups, an average plane from the CSS group has been defined; elevation angle data coming from CSS, CSL and both legs of TFA have then been projected onto this average plane. The variance explained with this approximation has then been evaluated and used as a measure of equivalence of the plane of covariance. RESULTS: Planar covariation law has been found to be valid for both legs of patients; moreover, percentages of explained variance when projecting all the data on a common plane remain higher than 97% for all groups, suggesting that the covariance plane is essentially equivalent in the CSS, CSL and both legs of TFA. When analysing the projection on a common plane, most of the differences can be identified in the second principal component. Moreover, differences are mostly present during the double support phases and at the end of single stance and swing. The timing of the differences in these two components is in a close relationship with that of the muscle synergies, in particular the module related to the hamstrings' activity. CONCLUSIONS: Results prove how, via defining a common reference plane for the elevation angles covariance, it is possible to build a low-dimensional description of the kinematics of prosthetic gait. Moreover, the equivalence of the reference plane improves the robustness of the identification of differences with respect to the control group. The relationship of these differences with the timing of the muscle synergy composed of hamstrings is coherent with the hypothesis that the two principal components of the elevation angles are related to whole leg length and orientation [3], since those muscles can act on both the knee and the hip. These preliminary results suggest that by combining muscle synergies and covariation law of elevation angles it is possible to build a low dimensional description of the neuromechanics of movement. [1] Leurs, F., et al. (2012). Gait Posture, 35(4), 647-652. [2] De Marchis, C., et al. (2019). J Neuroeng Rehabil 16(1), 132. [3] Ivanenko, Y., et al. (2007). J Neurosci, 27(41), 11149-11161.

MC2-4: Sensorimotor adaptation to novel dynamics modulated by closed-loop electrical muscle stimulation in human postural control system

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BACKGROUND AND AIM: The human postural control system transforms sensory information into appropriate motor commands to stabilize standing posture on various unstable conditions (Lockhart and Ting, 2007). However, its flexible adaptability has not been fully elucidated due to the lack of methodology. Here, we proposed a new method that flexibly changes the postural dynamics to elucidate the adaptation ability of the human postural control system. The underlying idea is that toppling torque, i.e., ankle dorsiflexion torque, is applied using electrical muscle stimulation (EMS) to tibialis anterior muscle (TA). Modulating the torque with the position and/or velocity of a center of mass (CoM) enables to flexibly and easily alter the postural dynamics. METHODS: Subject-specific parameters of EMS were first determined by estimating a transfer function of first order system that represents the relationship between the current intensity of EMS and the induced ankle dorsiflexion torques (Rouhani et al., 2016). In the experimental tasks, the participants were instructed to keep upright standing. After the baseline standing task for 60 s, EMS was applied to TA for 10 min. The current intensity of EMS was modulated with CoM position and/or velocity. During the EMS tasks, 14 sets of catch trials where a step dorsiflexion torque perturbation was applied with EMS were interleaved to measure the adaptive change of postural response. The series of the postural tasks was repeated under 3 different conditions in which the current intensities of EMS depended on the forward position and/or velocity of CoM. During tasks, surface electomyograms (EMGs) were recorded from plantar flexor muscles. RESULTS: The variance of CoM fluctuations during EMS gradually decreased throughout each task. Furthermore, the amplitude of EMG response in the catch trials was modulated with the CoM and its velocity for the adaptation to the CoM position- and velocity-dependent EMS, respectively. A PID control model (Peterka, 2000) was then fit to the CoM step response data to examine how the position- and velocity-dependent gains changed during the adaptation process. The proportional and derivative gains were estimated by an exploratory method as the value minimizing errors between measured and simulated CoM step response. The result demonstrated that the both gains were modulated in progress of adaptation to CoM position- and/or velocity-dependent EMS. CONCLUSIONS: Adaptation specific to CoM position- and/or velocity-dependent EMS increased the stability of a standing posture in each type of EMS, indicating the alteration of sensorimotor transformation in the postural control system. The closed-loop EMS system might be helpful to investigate the adaptation ability of postural control system to novel dynamics.

MC2-5: Motor adaptation to change of lower limb dynamics during maximal vertical jumping tasks

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BACKGROUND AND AIM: Humans can adapt their movements to an external perturbation or a novel environment. Mechanism of motor adaptation has been well studied in goal-directed movements such as arm reaching movement, revealing that sensory prediction errors act as a major driving force in motor adaptation (Shadmehr et al., 2010). However, little is known about the motor adaptation process for the movements aiming at maximizing performance with maximal effort such as vertical jump. Hence, this study aimed to investigate how the motor system adapts the vertical jumping movement to an external perturbation to reoptimize the performance. METHODS: Participants were instructed to jump as high as possible from an initial squat position without countermovement, with their arms crossed in front of the chest. The experimental tasks consisted of a baseline block (5 trials), a perturbation block (15 trials), and a washout block (10 trials). In the perturbation block, the neuromuscular electrical stimulation (NMES: 20 Hz, biphasic rectangular pulses with a pulse-width of 500 ĩs) was applied to the tibialis anterior muscle (TA) on both legs to perturb the ankle joint torque during the jump. The constant NMES was applied from 0.5 s before the initiation of the jump until the end of the movement. In order to reduce the effect of fatigue, a sufficient amount of intervals were interleaved between each trial (~15 s). Surface electromyograms (EMG) were recorded from the lower limb and trunk muscles. Ground reaction force and body kinematics data were measured using a force plate and motion capture system, respectively. Participants were provided about jump height immediately after each trial, which was obtained using a retro-reflective marker placed on their back. RESULTS: The NMES perturbation transiently reduced jump height in the early phase of the perturbation block comparing to the baseline block; however, the jump height gradually recovered as the jumping movement was repeated under the presence of NMES. In association with this performance recovery, we observed the muscle activity pattern globally changed during the process of adaptation: The EMG activity changed not only in the perturbed ankle joint muscles but also in the muscles spanning knee and hip joints. CONCLUSIONS: These findings suggest that the motor system gradually adapted their movement to the change of lower

limb dynamics induced by NMES on TA to maximize jump height. We would also like to emphasize that the NMES is applicable as an external perturbation method to investigate various whole-body motor adaptation tasks without employing costly perturbation device.

MC2-6: Visuomotor adaptation of ball-kicking movements specific to sensorimotor experience in manipulating feet

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Sophisticated soccer players can skillfully manipulate a ball with their feet depending on external environments. While the characteristics of upper-limb movements has been studied using motor adaptation tasks (Shadmehr et al., 2010), the ability of goal-directed control in lower-limb movements has not been fully elucidated. As compared with the upper-limb movements, the lower-limb specific properties such as a larger moment of inertia and longer sensorimotor delays make the movements more complicated. Hence, richer sensorimotor experiences of foot movements would explicitly affect the ability of the motor control. Therefore, we aimed to clarify how the skilled manipulation of lower limbs is acquired by comparing visuomotor adaptation during ball-kicking movements between participants with and without experience in playing soccer or futsal. Participants with experience had played soccer or futsal for at least 3 years. All participants performed ball-kicking movements with their right leg while standing with their left hand comfortably on a table. They were instructed to move a cursor representing the right toe position and shoot a virtual ball to a target virtually located at 5 m in front of their body. The ball, the cursor and the target on the horizontal plane were displayed in front of them. The ball had linear uniform motion depending on toe velocities and contact points with the toe. The experimental tasks were constructed by training, learning and washout trials. During the learning trials, the trajectories of the ball were rotated to 15° either clockwise or counterclockwise relative to the actual ball-direction. The toe trajectories were captured in real time using motion capture system. In each trial, errors were quantified between the target and the arrival point of the near the target. In learning trial, errors due to the visuomotor perturbation gradually decreased and converged. In the early phase of the washout trials, errors were opposite to the direction of visuomotor perturbation. The results indicated that the ball-kicking movement can be adapted to the novel visuomotor environment. Interestingly, there were differences in the motor performance between the two groups; smaller variability of errors in the training trials, the larger amount of error correction, and the speed to converge errors in the experienced participants. Furthermore, the variability of the toe trajectories was smaller in the experienced participants, suggesting that the experiences were better at repeating similar foot movements and didn't need to try a wide range of movements for the adaptation. Taken together, goal-directed lower-limb movements can be adapted to novel visuomotor environments. Moreover, the experience in playing soccer and futsal affected the motor performance and the process of motor adaptation, indicating that sensorimotor experience of foot movements is one of the significant factors for the skilled manipulation of lower limb.

Session Muscle Synergy 1

MS1-1: Low density, high surface area, multi-channel surface electromyography - A reliable tool to explore heterogeneity of quadriceps femoris muscle excitation

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BACKGROUND AND AIM: Muscle excitation is traditionally assessed by bipolar surface electromyography (sEMG), ignoring within muscle differences. Low density multi-channel sEMG (LDmEMG) layouts are enabling extraction of excitation patterns from signals recorded in multiple locations on a muscle. Quadriceps femoris excitation is frequently measured in both clinical and research settings due to its critical role in functionality. We designed a 64-channel LDmEMG configuration to cover all three superficial heads (vastus medialis (VM), rectus femoris (RF) and vastus lateralis (VL)), which enabled concurrent recording of overall quadriceps excitation. We aimed to (1) understand intra- and inter-session reliability of LDmEMG during different levels of isometric contractions and (2) test its ability to detect excitation patterns during these contractions. METHODS: We collected data from 5 healthy participants on two days separated by one-week. The experiment included 5 repetitions of 5-second maximum voluntary isometric contractions (MVIC) followed by 3 repetitions of 5-second contractions at 20%, 40%, 60% and 80% of MVIC in randomized order. LDmEMG were recorded from RF, VL and VM concurrently. Integrated data from the mid 3-seconds of each contraction were used to determine intra- and inter-session reliability (Intra-class correlation coefficient (ICC), two-way mixed, absolute) of each 64 individual LDmEMG channel for all contraction levels. We applied principal component analysis (PCA) to identify excitation patterns at different levels of isometric contractions. RESULTS: Overall, intra-session reliability of all channels showed excellent reliability (ICC>.90). Inter-session reliability was good to excellent for 60/64 channels (ICC>.75) at 40, 60, 80 and 100% MVIC and 47/64 channels at 20% MVIC. At 20% MVIC, channels over VM showed lower reliability, while the reliability of most VL and RF channels (41/46) was good to excellent (ICC>.75). Following PCA, the first component explained approximately 60% of variability, representative of overall quadriceps femoris excitation. The rest of the PCs (~40%) were suggestive of between and within muscle differences in RF, VL, and VM. Across all contractile intensities, five components were required to recreate approximately 80% of the original signal, suggesting a large proportion of similar complexity of control across intensities during an isometric contraction. There was an apparent clustering of the RF and VM channels into the individual muscles, with the compartmentalisation of the VL into two sections of excitation across participants and intensities, reflecting the proximal and distal half of the muscle. CONCLUSIONS: LDmEMG enables concurrent recording of muscle excitation from all three superficial heads of quadriceps femoris muscle with good to excellent intra- and inter-session reliability. It also enables identification of within muscle synergies, even in an isometric contraction. Future applications of LDmEMG will include healthy and clinical populations and different movement patterns.

MS1-2: Modulation of muscle synergies via supraspinal proprioceptive pathways

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BACKGROUND AND AIM: To organize movement in complex daily-life environments, the central nervous system of vertebrates must coordinate redundant degrees of freedom[1]. The resulting computational burden might be alleviated by the orchestrated activation of functionally related muscle groups, through modular patterns called muscle synergies[2]. In the presence of perturbations, the constant elaboration of sensory information from muscle spindles is crucial to ensure robust motion control through modulation of the temporal component of muscle synergies (the motor primitives)[3]. This ability is, however, negatively affected by ageing[4]. Previous research showed progressive degradation of spindles with aging and the resulting degradation of motor control[5]. Here, we attempted to investigate whether muscle spindle feedback is important for the modulation of motor primitives in young and older humans and in mouse models with and without feedback from muscle spindles. METHODS: For the human part, we recruited 19 young (age 27 ą 3 years) and 19 older adults (72 ą 6 y.). The mouse recordings were conducted on adult wild type (WT, n=5) and Egr3-/- (n=5) males. The Egr3-/- is a knockout mouse in which muscle spindles degenerate postnatally[6]. We recorded the ipsilateral electromyographic activity of eight lower/hindlimb muscles during walking on a treadmill, with and without sudden mediolateral displacements and accelerations of the belt. After the first recordings, WT mice underwent a lesion of the dorsal column medial lemniscus (DCML) pathway in the spinal cord. We estimated the Hurst exponent (H) of motor primitives to assess their long-term predictability[7]. RESULTS: Motor primitives had higher H in perturbed as compared to normal walking in young and old humans, in intact WT and in Egr3-/- mice. This was not the case in WT mice that underwent DCML lesion. Young human adults had a bigger increase in H than older adults in perturbed walking, as did Egr3-/- mice compared to WT. See Figure 1 for details. CONCLUSIONS: Our results show that perturbations can make motor primitives more predictable (i.e. "less random") over time. This evidence suggests that: a) old humans and muscle spindle-deficient mice partially lose the ability to modulate the predictability of primitives; b) preventing proprioceptive sensory information to reach the brain via DCML hinders the modulation of primitives in the presence of perturbations. We conclude that motor primitives for locomotion are modulated by proprioceptive sensory feedback through neural pathways that involve the brain. REFERENCES: [1] Bernstein, N. A. Pergamon Press (1967) [2] Bizzi, E. et al.. Science 253 (1991) [3] Santuz, A. et al. J. Physiol. 597 (2019) [4] Santuz, A. et al. iScience 23 (2020) [5] Shaffer, S. W. et al. Phys. Ther. 87 (2007) [6] Tourtellotte, W. G. et al. Nat. Genet. 20 (1998) [7] Hurst, H. E. Trans. Am. Soc. Civ. Eng. 116 (1951)

MS1-3: Muscles from the same muscle group can be independently controlled by the central nervous system during a synergistic action

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BACKGROUND AND AIM: It has been proposed that movements are produced through groups of muscles, or motor modules, activated by common neural commands. However, the neural origin of motor modules is still debated. Here, we used complementary approaches to determine: i) whether three muscles of the same muscle group (soleus, gastrocnemius medialis [GM] and lateralis [GL]) are activated by a common synaptic input; and ii) whether the distribution of neural drive between GM and GL can be modified by altering the mechanical requirements of the task. METHODS: Eighteen participants performed isometric standing heel raises and isometric plantarflexions (10%, 30%, and 50% of maximal effort). High-density surface electromyography recordings were decomposed into motor unit action potentials (> 2000 motor units) and coherence analysis was applied on the motor units spike trains. RESULTS: We identified strong common input to the motor neuron pools innervating each muscle, but little, if any, common synaptic input between pools innervating different muscles. Further, motor unit behaviour exhibited large between-muscle differences, such as later recruitment of GL compared to GM and soleus motor units and opposing changes in cumulative spike trains during the torque-matched plantarflexions. Finally, the feet position adopted during the heel raise task (neutral vs internally rotated) differentially affected the discharge of GL and GM motor units. CONCLUSION: These results provide conclusive evidence against the strong belief that all the "synergist" muscles are controlled by shared common synaptic inputs. It highlights the need to reconsider our approaches to identify motor modules. Electromyography decomposition could help to provide a more comprehensive descriptions of neural motor modules. FIGURE'S LEGEND: Between-muscle coherence estimated during the isometric heel raise (toes neutral). Panel A shows examples of the coherence between GM and GL for two participants: Participant #18 who exhibited no coherence and participant #5 who exhibited the highest coherence over the population tested. The horizontal lines represent the threshold of significance defined as the highest coherence value for frequencies > 100 Hz, at which no coherence is expected. The other panels show, for each participant, the frequencies at which a significant coherence was observed (Panel B for GM-GL, Panel C for GM-SOL, Panel C for GL-SOL). Some participants were discarded from this analysis as too few motor units were discriminated to allow this analysis. GM, Gastrocnemius medialis; GL, Gastrocnemius lateralis; SOL, Soleus.

MS1-4: Muscle synergies adaptations in presence of localized muscle fatigue during pedalling

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BACKGROUND AND AIM: The analysis of the modularity underlying the neuromuscular control of movement has been used as a tool for understanding motor adaptation and learning strategies. Previous studies analysed the changes in spatial composition or in the temporal commands in presence of external perturbations, in order to provide a compact representation of the neural mechanisms underlying motor adaptation. However, in most cases these perturbations were of biomechanical origin, driven either by mechanical constraints or by altered visual feedback in virtual scenarios [1-3]. Up to date, little is known on how modular control is altered in the presence of an induced localized muscle fatigue during the execution of a common rhythmical task. METHODS: Five healthy subjects (25ą2 yo) were recruited. All the experimental protocol was carried out in a motion analysis lab (BTS SMART-DX6000, 8 cameras). sEMG data have been recorded from 9 dominant leg muscles (BTS FREEEMG1000).

The experiment was divided into three main parts. The first and the last part (before and after the fatiguing protocol, respectively) consisted of a 3-min pedalling exercise executed at 70rpm, maintained through the use of a metronome, and with a power output of 100W imposed by a pedalling training roller. The second part of the experiment consisted in a dorsiflexion exercise, planned to induce a localized muscle fatigue in the Tibialis Anterior muscle, without involving other muscles, carried out with the subject comfortably sat on a chair while applying a dorsiflexion torque against an elastic band, until the subject was not able to maintain that force anymore. The task was segmented based on the recorded kinematics, with the beginning of each pedalling cycle defined when the reflective marker placed on the pedal was in the top dead centre. Muscle synergies of the PRE-fatigue trial were extracted by means of Non-Negative Matrix Factorization (NNMF), so to obtain synergy vectors WPRE and synergy activation coefficients CPRE. Synergy vectors WPRE were then fixed to reconstruct muscle activity of the first cycles of the post fatigue trial (soon after task failure, POST-1) and the last cycles (after 2 minutes of pedalling after fatigue, POST-2) by using Nonnegative Reconstruction (NNR). RESULTS: All the trials (PRE, POST-1 and POST-2) proved to have the same dimensionality for all the subjects (VAF > 0.9 by extracting five muscle synergies). By using WPRE for reconstructing POST-1 and POST-2 trials, the reconstruction VAF turned out to be comparable to that of the PRE trial, thus indicating a preservation of the spatial structure. The main differences were found in the reduction of the recruitment of W1, W2, W4 and W5 during POST-1. While the activity of W1 and W4 returns the baseline values during POST-2, the alterations observed in W2 and W5 are maintained. CONCLUSIONS: These results suggest that in order to carry out a task in the presence of localized muscle fatigue, the central nervous system still uses the same spatial organization, by changing the recruitment of the fatigued muscles together with its synergists. The observed changes suggest the presence of significant adaptations of the used pedalling strategy, which probably consists of an higher down-stroke force application with the pedal controlled by the non fatigued leg that can be responsible for the changes in the activations of the first, second and fourth motor modules. [1] De Marchis, C., et al. (2018). Sci Rep, 8(1), 12657. [2] Berger, D. J., et al. (2013). J Neurosci 33(30), 12384-12394. [3] Zych, M., et al. (2018). J Neurophysiol, 121(1), 163-176.

MS1-6: Extraction of muscle synergies from high-density electromyograms for rapid neuro-mechanical modeling: towards applications in post-stroke locomotion

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BACKGROUND AND AIM: The clinical assessment of post-stroke neuromusculoskeletal function ideally requires rapidity and accuracy simultaneously. Nowadays, clinicians use rapid evaluations based on crude visual observations of a simple locomotion task (i.e. the 10-meter test), where the final assessment depends exclusively on subjective assessment. On the contrary, highly accurate evaluation of neuromusculoskeletal function post-stroke could be achieved in a well-equipped biomechanical laboratory. However, this involves lengthy set-up, data acquisition and offline data analyses that could become available only days or weeks after the initial assessment, thereby no longer reflecting the patient's actual state. The ability to capture the patient's true neuromuscular activity as well as joint kinematics is key for neuromechanical simulations, but the process of muscle localization for electromyography (EMG) electrode placement and joint angle measurements are lengthy tasks, not

always viable in the clinical environment. The proposed way to solve these issues is to develop an automated procedure to reduce the high-dimensional (HD) space of the EMG channels, surrounding the lower leg, in muscle specific activation profiles and use those as inputs to a newly developed framework for real-time modeling of neuromusculoskeletal system for estimation of internal mechanical forces. METHODS: the process of muscle identification and electrode placement is replaced by the flexible garment with an integrated grid of 64 equally distributed electrodes around the lower leg. The HD-EMG signals belonging to a muscle group are segmented via the non-negative matrix factorization (NNMF). The channel-space matrix is reduced to a small set of primitives, or control signals, along with a set of weighting factors. The first NNMF-decomposed matrix gives temporal information about muscle activation primitives, while the second one identifies which muscles are synergistically activated by those primitives, in channel space. The extracted primitives become the driver of the musculoskeletal model in order to retrieve the subject-specific representation of the underlying neuromechanical processes. RESULTS: via the NNMF, two primitives controlling the lower leg muscles were obtained: the first one related to locomotion push-off phase and involved the synergistic activation of the calf muscles in order to provide the right push to go forward with the step; the second primitive related to the swing phase and engaged mainly the tibialis anterior to ensure foot clearance over the ground and preparation of the foot for the following heel strike. The primitives extracted from the HD-EMG resemble the ones found placing singles electrodes on each muscle belly ($R\bar{e}$ = 0.85 - 0.95). The musculoskeletal model driven by HD-EMG primitives was able to reproduce with good accuracy ($R\bar{e}$ = 0.8 - 0.9) experimental ankles torque during the gait at different speeds. CONCLUSIONS: This paper presented a framework for the rapid extraction of muscle synergies and musculoskeletal forces. The online representation of the patients' musculoskeletal properties allow to reduce the time gap during the process of the data acquisition and post processing advanced analysis, being a promising asset in clinical environment. Future work will extend the framework to operate in real-time and will develop a new type of electrode based on highly wearable textile garments. This is expected to further improve translation to clinical settings.

Session Neuromechanics 1

N1-1: Region-specific electromyographic activity within the biceps femoris long head depending on knee joint angle during maximal voluntary isometric knee flexion

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BACKGROUND AND AIM Surface electromyographic (EMG) has been used to estimate the force production properties of individual muscle components in previous studies. The studies suggested that the degree of contribution to the production of joint torque in the individual hamstring muscles estimated from EMG differs depending on knee joint angle during maximal voluntary isometric knee flexion (MVCKF). Recent studies showed that the biceps femoris long head (BFlh), semitendinosus (ST), and semimembranosus (SM) are, respectively, divided into several regions by their multiple motor nerve branches (1), suggesting that each region may be regulated in a different way by the central nervous system (2). Thus, it is possible that each region within the individual hamstring muscles nonuniformly contributes to producing knee flexion torque at several knee joint angles during MVCKF. However, no study has examined EMG activity of the regions within each hamstring muscle at each knee joint angle during MVCKF. The purpose of this study was to compare EMG activities among the regions within the individual hamstring muscles at several knee joint angles during MVCKF. METHODS Sixteen participants performed MVCKF at 0°, 30°, 60°, 90°, and 120° of knee flexion (0° = full extension of knee joint). After the borders of the individual hamstring muscles were carefully identified with an ultrasonic apparatus at 0° and 120° of knee flexion, surface electrodes were placed on the proximal, middle, and distal regions within each hamstring muscle as far away from the muscle borders as possible. The root mean square (RMS) value of EMG data was calculated and normalized by the maximal RMS value of each region across all joint angles and trials as % RMS. RESULTS The results revealed that %RMS of BFlh was higher in the middle region than in the proximal region at 0° ($P = 0.017$, Cohen's $d = 0.925$) of knee flexion during MVCKF (Fig. 1A). The %RMS in the distal region of BFlh was higher than in the proximal region at 90° ($P = 0.008$, Cohen's $d = 1.001$) and 120° ($P = 0.003$, Cohen's $d = 1.175$). Similarly, the distal region of BFlh showed a higher %RMS than the middle region at 90° ($P = 0.011$, Cohen's $d = 0.984$) and 120° ($P = 0.004$, Cohen's $d = 1.027$). For ST and SM, no regional difference in %RMS was found over all knee joint angles (Fig. 1B and C). CONCLUSION The results suggest that the middle and distal regions of BFlh greatly contribute to producing knee flexion torque at knee extended and flexed positions, respectively, whereas each region of ST and SM uniformly contributes to generating that at all knee joint angles during MVCKF. The region-specific activity of BFlh may be related to the neuroanatomical characteristic of multiple nerve branches dividing BFlh into several regions. These findings would provide a better understanding of the force production property of each region within the hamstring muscles. 1) Woodley and Mercer, Cells Tissues Organs, 2005. 2) Hegyi et al., Scand J Med Sci Sports, 2018.

N1-2: Neuromuscular responses in the ankle plantarflexors during rapid, unexpected perturbations

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BACKGROUND AND AIMS: In our everyday lives, we continuously negotiate complex environments and unpredictable terrain. Our ability to stay upright in the face of obstacles, such as a curb, hole, or bump in the ground, is quite remarkable. However, much of our knowledge regarding human locomotion has come from studies conducted under steady-state conditions on level surfaces. Thus, we understand relatively little about how humans adjust muscle-tendon function to recover during unexpected perturbations. Our previous work has shown that humans use distal lower-limb joints (i.e.: the ankle) to absorb energy and successfully recover from perturbations across a range of heights ranging from 5cm to 20cm [1]. However, the muscle-tendon behaviour and motor control strategies that accompany these joint-level responses are not yet understood. Previous studies of unexpected drop landings in birds highlight the influence of series elasticity within the muscle-tendon unit (MTU) which acts as a buffer to rapidly absorb mechanical energy and protect muscle fascicles from potentially injurious strains [2]. In this study, we aimed to determine how humans coordinate neuromuscular function in the ankle plantarflexors to maintain upright, rhythmic hopping during rapid, unexpected perturbations.

METHODS: We asked subjects to perform steady-state hopping at their preferred frequency while we collected lower-limb joint kinematics, kinetics, surface electromyography (EMG), and B-mode ultrasound. Subjects began hopping on a platform elevated 20cm above the level ground; between the 10th and the 20th hop cycle we elicited an unexpected perturbation via removal of the platform and the subjects continued to hop following the perturbation. An eight-camera motion analysis system (Vicon, Oxford, UK) was used to capture the three-dimensional (3D) positions of 36 reflective markers attached to the pelvis and lower limbs. MTU lengths were computed from a scaled musculoskeletal model and motion capture data. 3D ground reaction forces applied to the left and right legs were measured during hopping using a static instrumented split belt treadmill (Bertec, OH, USA). Surface EMG was used to record muscle activitations from medial gastrocnemius (MG), lateral gastrocnemius (LG), soleus (SOL), and tibialis anterior (TA) (Biometrics, Newport, UK). MG muscle fascicle length was measured from B-mode ultrasound images (Telemed, Lithuania). RESULTS: Muscle activation increased in the plantarflexors (MG, LG, and SOL) during both the aerial and ground contact phases of the perturbation, when compared to normal hopping. These increases in muscle activation were accompanied by increased MG fascicle shortening prior to ground contact and increased MG fascicle lengthening during the ground contact phase of the perturbation. However, during the perturbation the MG MTU remained near-isometric prior to ground contact, suggesting that increased co-activation of the ankle plantarflexors (MG, LG, and SOL) and dorsiflexors (TA) enables internal MG fascicle shortening prior to ground contact. CONCLUSIONS: Humans adjust the neuromechanical behaviour of their ankle plantarflexors through alterations in muscle activation and fascicle dynamics to successfully recover from an unexpected perturbation and avoid a fall. Increased fascicle shortening immediately prior to the perturbation may provide a mechanism to enable favourable contractile conditions upon ground contact and limit muscle fascicles from potentially injurious strains during this rapid energy dissipation task. The findings of this study provide fundamental insights into the mechanisms for locomotor stability during unexpected perturbations and have rich potential to inspire the future design of lower-limb assistive devices including prostheses and exoskeletons capable of performing within real-world environments. REFERENCES [1] Dick, TJM et al. (2019). Interface, 16(159), 20190292. [2] Konow, N et al. (2012). Proc B, 279(1731), 1108-1113.

N1-3: M-wave-H-reflex recruitment curves obtained by single pulse nerve stimulations and nerve stimulation trains

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BACKGROUND AND AIM: The H-reflex (H) as elicited by a single pulse electrical nerve stimulation under low-level voluntary background activity is widely used to investigate Ia-excitability [1]. The use of a stimulation train to obtain multiple H responses is a different way to assess spinal contributions to electrically-stimulated contractions [2]. However, it remains unclear if H responses elicited by a stimulation train are comparable to those elicited by single pulse stimulations. Therefore, we compared the M-wave (M)-H recruitment curves obtained by single pulse stimulations under background activity (SB) with recruitment curves obtained by stimulation trains (STs). As it is not possible to monitor constant background activity during stimulated tetanic contractions, a third recruitment curve was obtained by single pulse stimulations under no background activity (SR). METHODS: Participants laid prone on a dynamometer bench (IsoMed 2000, D&R Ferstl GmbH, GER). M-H recruitment curves were constructed for electrical stimulations of the tibial nerve (DS7AH, Digitimer, UK) from soleus EMG responses (AnEMG12, Bioelettronica, IT; 5 kHz). Stimuli for SB (10% of maximum activity) and SR were delivered as 1-ms square-wave pulses and STs were delivered over 2-s at 20 Hz to generate tetanic contractions. Stimulation intensity ranged from below M- and H-thresholds to 1.2 times the intensity required to elicit the largest M (Mmax). M and H responses were determined as peak-to-peak amplitudes. Three M-H recruitment curves were constructed from STs based on: 1) The first stimulation (ST1), 2) mean responses of stimulations 2-20 (ST2-20) and, 3) mean responses of stimulations 21-40 (ST21-40). For ST2-20 and ST21-40, the coefficient of variation (CV) for M and H was calculated. RESULTS: Preliminary data (n=1) showed that H threshold and motor threshold (MT) were slightly lower from SB compared with the other conditions. Mmax from SR and SB was ~20% less than Mmax from all ST conditions. Hmax was similar from SR, SB and ST1 (56-59% Mmax), and it occurred at similar relative stimulation intensities (1.1-1.3 MT). In comparison, mean Hmax from ST2-20 and ST21-40 were depressed by 43% and 33% Mmax, respectively. CV for M from ST21-40 ranged from 0.6-42.2% and was below 10% for stimulation intensities >1.3 MT. CV for H from ST21-40 ranged from 13.8-91.2% across stimulation intensities, but was only ~20% for stimulation intensities from 1.1-1.4 MT. CONCLUSIONS: Based on the preliminary data, M-H recruitment curves differ between stimulation protocols. However, from ST21-40, ST conditions seem to provide stable M and H responses for stimulation intensities that represent the descending part of the H recruitment curve. H differences across single pulse and STs might be due to an interaction between recurrent and homonymous inhibition and persistent inward currents, whereas M responses might be influenced by hyperpolarisation [3]. REFERENCES: [1] Knikou M, J. Neurosci. Methods 117(1): 1-12, 2008. [2] Bergquist AJ et al., J. Appl. Physiol. 110(3): 627-37, 2011. [3] McComas AJ et al., Muscle Nerve 17(6): 599-607, 1994.

N1-4: Concurrent assessment of neural and mechanical motor unit properties with high-density surface electromyography ultrasound-transparent electrodes

Eduardo Martinez-Valdes[1], Francesco Negro[2], Alberto Botter[3], Giacinto Cerone[3], Deborah Falla[1], Patricio Pincheira[4], Glen Lichtwark[4], Andrew Cresswell[4]
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Introduction: Previous studies attempting to understand the relationship between muscle mechanics and neural activity have used simultaneous quantification of muscle movement (ultrasound images, US) and neural activation (surface electromyography, EMG) utilising EMG approaches with low spatial sampling from different muscle regions. This issue has been addressed by the introduction of high-density (HDEMG) electrodes transparent to US. This new approach allows the mechanical properties of muscles and the behaviour of single motor units to be recorded simultaneously, on the same region of interest. This provides a great advantage as motor unit firing patterns could be directly correlated to changes of the muscle's fascicles. However, HDEMG motor unit decomposition and US-based fascicle tracking have never been used simultaneously. This project aimed to investigate the influence of dynamic changes in fascicle length and muscle architecture on motor unit firing properties. Methods: EMG signals were recorded from 8 male participants (26 (3) years) using a silicon rubber matrix of 32 electrodes while performing ankle-isometric dorsiflexion at 20% and 40% max. force (MVC), at 0° and 30° of plantarflexion during sinusoidal contractions (frequency: 0.5Hz, modulation amplitude: 5% MVC). At the same time, US images of tibialis anterior fascicles were captured using B-mode US at 80 fps using a 96-element multi-frequency transducer. Images were synchronised frame-by-frame with EMG data. The relationship between changes in fascicle length, pennation angle and discharge rate were analysed for units matched by recruitment threshold across conditions. In addition, the cross-correlation and delay (lag) between discharge rate vs force (DR-F, force produced at the tendon level), discharge rate vs fascicle length (DR-L) and fascicle length vs force (L-F), was quantified across all conditions. Results: On average, 6 (3) motor units were identified per subject across all contractions. DR-F, DR-L and L-F were correlated by 76.4 (4.4)%, 70.3 (3.3)% and 88.0 (1.8)%, respectively. We identified a significant delay between force, discharge rate and fascicle length (DR-F: 157.0 (6.1) ms, DR-L: 81.3 (7.8) ms and L-F: 72.6 (4.3) ms, $p<0.0001$). These delays were not influenced by force level nor joint angle. Discharge rate, fascicle length and pennation angle increased significantly with force ($p<0.001$) and were not influenced by changes in joint angle ($p>0.05$). Conclusion: This study is the first to demonstrate the feasibility of recording single motor unit activity with HDMEG US-transparent electrodes. The findings show a close relationship between the force measured at the tendon level, changes in fascicle length and discharge rate, allowing quantifying the delay between each of these mechanisms. Future studies, should aim to combine US and HDEMG motor unit decomposition in order to better understand the interactions between changes in neural activity and muscle mechanics.

N1-5: Achilles tendon shear wave speed tracks the dynamic modulation of standing balance

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BACKGROUND AND AIM: Standing balance performance is often characterized by sway, as measured via fluctuations of the center of pressure (COP) under the feet. For example, COP metrics can effectively delineate changes in balance under altered sensory conditions. However, COP is a global metric of whole-body dynamics and thus does not necessarily lend insight into the underlying musculotendon control. We have previously shown that shear wave tensiometers can track wave speeds in tendon as a surrogate measure of the load transmitted by the muscle-tendon unit. The purpose of this study was to investigate whether shear wave metrics have sufficient sensitivity to track subtle variations in Achilles tendon loading that correspond with postural sway. METHODS: Sixteen healthy young adults (26 ą 5 years) stood for 10 s with their eyes open and closed. We simultaneously recorded COP under the feet and shear wave speed in the right Achilles tendon. Pearson's correlations examined the relationship between Achilles tendon shear wave speed and anteroposterior COP for every trial. We also compared the normalized power spectral density of Achilles tendon wave speed and COP using a Wilcoxon signed-rank test. We similarly compared the magnitudes of tendon force (derived from calibration parameters) between eyes open and eyes closed conditions. Paired-samples t-tests assessed differences between visual conditions (eyes open, closed) on common summary metrics of COP and Achilles tendon wave speed, such as Standard deviation and Velocity. RESULTS: We examined 64 trials of quiet standing. We found that Achilles tendon shear wave speed closely tracked ($r > 0.95$) dynamic fluctuations of the COP in the anteroposterior direction. Achilles tendon wave speed fluctuations significantly increased during

standing with eyes closed, mirroring increases in COP fluctuations. Spectral analysis revealed that Achilles tendon shear wave speed exhibited similar spectral patterns to COP, but relatively more signal power at frequencies > 4 Hz. Tendon force was significantly greater during the eyes closed condition compared to the eyes open condition. CONCLUSIONS: These results demonstrate that tendon wave speed can track the subtle variations in Achilles tendon loading that modulate COP in standing. Additionally, wave speed fluctuations were sufficient for quantifying altered balance performance without visual feedback. Hence, shear wave tensiometry exhibits the sensitivity to investigate the muscular control of quiet standing. The force sensitivity of the tensiometer technology brings about a unique opportunity in biomechanics and motor control, suitable for investigating muscle-tendon loading during postural control, force steadiness experiments, and fatigue studies.

N1-6: The role of estrogen on reciprocal inhibition of the Soleus

Samuel Acuña[1], Jamie Kunnappally[1], Pauline Phan[1], Subaryani Soedirdjo[1], Hyungtaek Kim[2], Luis Rodriguez[2], Conner Hutcherson[1], Yu-Chen Chung[1], Yasin Dhaher[1]
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BACKGROUND AND AIM: Our prior work indicates that estradiol has an undisguisable effect on motor neuron excitability. In this study, we seek to explore the effect of estrogen at the network level with a primary focus on a neuronal network that is defined on the net as inhibitory. METHODS: We conducted a peripheral nerve stimulation paradigm to quantify changes in the state of the reciprocal inhibition in a model with naturally fluctuating hormones: young women who are non-users of oral contraceptives. We measured reciprocal inhibition 15 separate times on days spread throughout the menstrual cycle, while also documenting each participant's current level of estrodiol. Participants laid prone while performing isometric ankle plantarflexion to generate a torque of 10% of their maximum generated torque, found using a maximum voluntary contraction protocol. While plantarflexing, we stimulated the common peroneal nerve at least 10 times and recorded the reciprocal electromyographic (EMG) response of the soleus muscle at 2000 Hz using a pair of gel electrodes (diameter = 1 cm, distance = 2.5 cm) placed according to SENIAM recommendations. EMG signals were rectified and low-pass filtered using a 4th order Butterworth filter at 500 Hz. Reciprocal inhibition was measured as the difference between the mean pre-stimulus EMG (from a window 40-5 ms before stimulation onset) and the minimum EMG (from a window 30-60 ms after stimulation onset), and expressed as a percentage of the maximum voluntary EMG. A one-way ANOVA with posthoc pairwise comparison tested for significant differences in the reduction of EMG amplitude. RESULTS: This ongoing study has currently enrolled 7 women, and we present results from one subject thus far. We observed a consistent depression in EMG activity around 50 ms after the stimulus in every testing session. However, we found that the amplitude of this depression changed over the 15 testing sessions, presenting significantly less inhibition in the days leading to peak estrodiol ($p < 0.001$). CONCLUSIONS: Our preliminary data indicate that the amplitude of the reciprocal EMG response of the Soleus modulates with the levels of circulating estradiol concentration. Understanding the changes in spinal neural state associated with estrogen may provide insights on our understanding of the effect of endogenous hormones on neuromuscular control with significant clinical implications.

Session Pain 1

P1-1: People with chronic low back pain display an altered distribution of erector spinae activity during a singular mono-planar lifting task

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Previous studies utilising high-density electromyography (HDEMG) have revealed subtle differences in the distribution of the superficial lumbar paraspinal muscle activity during both static and dynamic tasks in people with low back pain (LBP). Specifically, people with LBP present with a cranial shift in the distribution of erector spinae (ES) activity. Although these studies have revealed an altered distribution of lumbar paraspinal muscle activity in those with LBP, the findings were limited to the specific region evaluated (i.e. lumbar ES unilaterally spanning a region from approximately L2 to L5) and the findings were also potentially influenced by fatigue since the tasks were performed repetitively or were sustained. Here we extend previous work by performing a comprehensive mapping of both lumbar and thoracolumbar muscle activity during a single repetition of a mono-planar lifting task in order to specifically examine the influence of LBP in the absence of a fatiguing task. Additionally, we record spinal kinematics in a segmental arrangement to quantify differences between movement in the lumbar and the thoracolumbar regions of the spine. Ethical approval was granted from the University of Birmingham. Eleven LBP (5 men; 32.5ą16.3years) and fourteen control (CON) participants (6 men; 27.4ą11.4years) completed this study. HDEMG was acquired from the ES using four 64-channel (13x8) semi-disposable HDEMG grids (two grids bilaterally) placed over the lumbar and thoracolumbar ES. For analysis, the upper and lower girds on each side were combined, and the activity was considered for the combined left and right lumbar and thoracolumbar regions. The spatial distribution of muscle activity was quantified from the centre of activity in the cranio-caudal y-axis (y-barycentre of the centroid); and the homogeny of signals (entropy). Reflective kinematic surface markers were placed in triangular arrangements over the lumbar and thoracolumbar trunk regions to investigate the individual contributions of these regions to the lifting movements. The dynamic task involved lifting a 5kg weighted box between two anterior shelves at knee (S1) and sternum height (S2). Participants completed one cycle of lifting comprising movement of the box from S1-S2, 2 seconds rest, and S2-S1. No differences in spinal kinematics were identified between groups throughout the task (P>0.05), likely reflecting the standardised nature of the task. For all movements, the distribution of ES activity was centred systematically more cranially in the LBP group (P<0.05). For the movement from S1-S2, the LBP y-barycentre was 5.56mm more cranial than the CON group and for the movement from S2-S1, the LBP y-barycentre was 6.47mm more cranial. LBP participants also displayed a less homogenous spatial distribution of ES activity throughout the task, reflected as systematically lower entropy for all movements (p<0.05). These findings indicate that people with LBP engage more cranial regions of the ES during lifting, likely reflecting a less biomechanically favourable motor strategy. This activation pattern suggests that individuals with LBP utilise a less effective biomechanical strategy even in the absence of fatigue caused by a prolonged testing period. These novel findings may have relevance for ongoing pain and facilitate the development of novel rehabilitation approaches.

P1-2: The influence of vibration on trunk proprioceptive control in people with and without low back pain

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BACKGROUND AND AIM: Adaptations in lumbar sensory-motor control are common in people with low back pain (LBP) (Ebenbichler et al. 2001), and compromised lumbar proprioceptive input can contribute to a loss of trunk control and even LBP chronification (Meier et al. 2018). Muscle spindles represent the main proprioceptive receptors. Vibration applied over muscle and therefore muscle spindles, generates an illusion of limb movement (Proske and Gandevia, 2012). This study examined the contribution of the lumbar muscle spindles to trunk control in people with LBP versus asymptomatic controls (AC) by measuring the trunk repositioning error with and without vibration of the lumbar erector spinae. METHODS: Fourteen AC (age: 32.5ą4.8 years) and fourteen people with LBP (age: 37.8ą9.0 years, average pain: 5.6ą2.1/10) participated. An inertial motion sensor attached to the 3rd thoracic spinous process measured the accuracy in adopting and returning to a neutral trunk position after sagittal movement (50° trunk flexion). Lumbar vibration was randomly applied during trials. Three trials were executed for each condition (Vib, No-Vib). The mean trunk repositioning error (TRE) was calculated and statistically evaluated using a two-way repeated-measure analysis of variance (ANOVA) within the two vibration conditions and between the two groups. RESULTS: The mean TRE increased significantly in the LBP group ($p<0.001$) under the Vib condition (5.0ą2.6°) compared to the No-Vib (1.9ą1.7°). No significant differences were found for the AC group ($p>0.05$) between the Vib (2.9ą2.2°) and No-Vib (2.4ą1.6°) condition. The groups did not differ in their mean TRE under the No-Vib condition ($p>0.05$) whereas the TRE was significantly higher in the LBP group compared to the AC under the Vib condition ($p=0.037$). CONCLUSIONS: People with LBP were unable to compensate for the vibration-induced proprioceptive illusion. This study highlights the pivotal importance of lumbar muscle spindles in controlling trunk motion accuracy in people with LBP. The disturbance induced by the vibration generated a significant impairment of trunk control in people with LBP and enhanced the specificity of the trunk repositioning error test.

Session Rehabilitation 1

R1-1: Morphometric and activation characteristics of the vastus medialis muscle after ACL graft re-tear

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BACKGROUND AND AIM: After primary ACL reconstruction, a second injury likely occurs within a time frame of 24 months. Rehabilitation programs aim therefore to re-establish function and to address modifiable risk factors for re-injury. An important risk factor which can be modified are neuromuscular alterations. This study was designed to delineate possible inter-relations between activation and morphometric characteristics of vastus medialis muscle in competitive soccer players after a second ACL tear. METHODS: Twenty male soccer players (age: 29 (SD 6) years, 19 non-contact injury) were examined at the re-torn (R) and uninjured (C) sides before the revision surgery and 270-4,620 days after the first ACL injury. Patients performed isometric knee extension (KE) at 80% maximum voluntary torque for 33 seconds. Activity of the vastus medialis muscle was recorded using a surface array (Delsys). The signals were decomposed into individual motor unit (MU) action potentials. Only samples with at least ten correctly identified MUs were used for further analyses. MU action potential (AP) size of higher-threshold (> 20%) MUs served as outcome measures. Muscle biopsies were obtained at the end of the ACL revision surgery from the R side only. Samples were frozen in methylbutane, cooled in liquid nitrogen and mounted, cut with a cryostat and subsequently used for enzyme histochemical and cytophotometrical analyses. Differences between sides as well as linear relationships between muscle fiber morphology and MU activation were quantified using effect size (d) and Pearson's r statistics, respectively. RESULTS: On average, 121 muscle fibers per patient were analyzed (total: 2,423 fibers). Type I and II mean fiber diameter (I: 68 ĩm (13), II: 73 ĩm (14)) and fiber proportion (I: 40% (14), II: 60% (13), df = 19, $p < 0.01$, d = -0.8) differed significantly. The number of MUs recruited above 20% KE was on average lower at the injured side (R: 22 (9), C: 29 (8), df = 15, $p < 0.02$, d = -0.6). Nevertheless, no relevant differences for MUAP size could be proven between sides (R: 0.16 mV (0.10), C: 0.19 (0.16), df = 15, $p > 0.4$, d = -0.2). Body mass adjusted KE of R correlated with KE symmetry (r = 0.76, $p < 0.001$) and with MUAP size (r = 0.65, $p < 0.01$). MUAP size was inversely related to the fiber type diameter difference (r = -0.76, $p < 0.001$). CONCLUSION: The range in time since the first ACL injury can account for differential neuromuscular adaptations. However, patients with a greater KE symmetry performed better at their injured side. This supports the application of the limb symmetry concept. Moreover, a larger difference between fiber types (in favor of type II) probably assists neuromuscular compensations, even after a recurrent knee trauma.

R1-2: Preliminary results on spatiotemporal and kinematic parameters after surgical intervention in patients with an equinovarus foot deformity following stroke

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BACKGROUND AND AIM: Equinovarus is the most frequently (10-20 %) seen foot deformity in the affected leg after stroke [1],[2]. The equinovarus foot affects all phases of the gait cycle, initial contact occurs at other foot regions than the heel, during stance ankle stability and dorsiflexion reduces, and in swing phase the clearance is decreased. Consequently, this foot deformity severely compromises walking capacity, the patient risks falling and is often unable to walk unassisted or without orthotic device [3],[4]. Surgical correction of the equinovarus foot deformity shows promising results in improving walking ability [3],[5],[6]. However, at present it is not clear which patients benefit from the surgical intervention and little is known about the effects on walking performance. An extensive study started to gain more information on these topics; this abstract presents some preliminary results. METHODS: Four subjects finished the study protocol. All subjects are adult stroke survivors with chronic hemiplegia (> 6 months after stroke) and walking disabilities due to equinovarus foot deformity. The subjects underwent an intervention of standard surgical techniques, i.a. Split Tibialis Anterior Tendon Transfer (SPLATT), to correct equinovarus foot deformity. In the 2-month period before the surgery and 6 months after the surgery, an instrumented gait analysis is performed using Vicon (LowerBody Plug-in Gait). The subjects were asked to perform several steps bare foot. RESULTS: The four subjects showed different degrees of impaired gait. Two subject with more severely impaired gait had a walking velocity of 0.15 and 0.25 m/s, the other two subjects with less severely impaired gait had a walking velocity of 0.61 and 0.89 m/s. The sagittal ankle angles of the subjects with less severely impaired gait showed positive results after surgery: increased dorsal flexion during initial contact, terminal stance, and the entire swing phase (Figure 1). The other two subjects did not show clear improvement on this kinematic parameter. All subjects improved their step length on the non-affected side after surgery, ranging from 3.4 to 5.6 cm increase. This result suggests increased tibial progression during stance on the affected side. CONCLUSIONS: These preliminary results are promising, all subjects tend to improve tibial progression during stance phase and half of the subjects improved their clearance during swing phase. Continuation of this study will provide more insight on spatiotemporal and kinematic changes after the SPLATT procedure. [1] Deltombe et al, Critical ReviewsTM in Physical and Rehabilitation Medicine, 2007 [2] Lawrence, Foot and Ankle international, 1994 [3] Renzenbrink et al, Journal of Rehabilitation Medicine, 2012 [4] Forghany et al, Gait and Posture, 2014 [5] Bofelli, The Journal of Foot and Ankle Surgery, 2014 [6] Gianotti, European Jounal of Physical and Rehabilitational Medicine, 2015

Session Rehabilitation 2

R2-1: Onsite feedback for recognizing functional mastication with surface EMG

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BACKGROUND AND AIM: Changes in masticatory function should be augmented especially for elderly, because not enough blushing causes periodontal disease, temporomandibular disorders, and further sometimes links to dementia. Moreover, unilateral chewing could enlarge masticatory trouble. Since denture wearers are subject to mild cognitive impairment, clenching properly is required everyday life. To achieve this strategy, we have tried to develop an onsite feedback of masticatory function at a reasonable price. METHODS: SEMG signals with a handmade data acquisition unit assembled by two uEMG units with each concentric bipolar sensor (OT Bioelectronica) which links to IoT chip (ESP32).

Measured data was transformed to the csv file format. Note that analog data was measured with uEMG units and was converted with 1 kHz sampling at the wireless data logger. This device operates without the internet services. Further, we designed a masticatory function feedback GUI by C#. That is, we estimated RMS profile, sliding a 300 ms interval every 10 ms, for each consecutive chewing stroke of both sides, then identify the chewing side and the number of times. We measured SEMG signals at masseter and temporalis. RESULTS: RMS profile at each chewing stroke of both sides was effective to count the chewing stroke. The threshold was adjusted based on the maximum during clenching at preparation. The threshold for counting the chewing times was determined by the maximum of the RMS profiles among both sides, the number of chewing was different due to unilateral chewing. The malocclusion might be explicitly understandable, because the RMS profile at left masseter was larger and varied irregularly than that at right one. DISCUSION: Recently, IoT chips has become popular at reasonable price. We confirmed the function of Web server by adopting the same csv file data. Note that the IoT chip equips the A/D convertor and WebServer modules. Kobayashi et al. showed that a prototype design for wireless EMG capturing system with stimulation feedback Jiang et al. proposed IoT-based remote facial expression monitoring system with SEMG signal. Yang et al. presented a scalable IoT system for real-time biopotential monitoring and a wearable solution for automatic pain assessment via facial expressions. It is a wearable device with a bio-sensing facial mask is proposed to monitor pain intensity of a patient by utilizing facial SEMG. The wearable device works as a wireless sensor node and is integrated into an IoT system for remote pain monitoring. ACKNOELEDGEMENT: Assembling modules has been supported by Omokawa Denshi Sekkei Inc., Niigata Pref. [1] D. A. Deniz and Y. Kulak Ozkan, "The influence of occlusion on masticatory performance and satisfaction in complete denture wearers," J Oral Rehabil, vol. 40, no. 2, pp. 91-8, Feb 2013. [2] H. Kobayashi and Y. Tatsukami, "A prototype design for wireless EMG capturing system with stimulation feedback," in 2013 6th Int Confi

R2-2: Influence of imposed head movements on head kinematics

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BACKGROUND AND AIM: Having adequate head support is of great importance for individuals in wheelchairs that have problems with head stabilization. Currently, the majority of head support systems are static devices that fixate the head in one position. This has limitations, because activities of daily living (such as reading or eating) and posture changes might require different head positions. We therefore have the goal to develop an intelligent head support system in which the user can intuitively control the head position while head stabilization is ensured. As a first step in this development, we aimed to study head kinematics in free space and investigate how individuals respond to imposed head movements. METHODS: Non-impaired individuals participated in this study. Participants moved their head in free space and were also placed in a measurement device (see Figure 1) which allowed us to move the head. Markers were placed on the head, torso and the head support system to study the movements of these segments using an opto-electronic motion analysis system. Participants performed flexion/extension, lateroration, lateroflexion and the combination of laterorotation and lateroflexion (latter one only in the measurement device). RESULTS: A total of 19 participants were included in this

study. We analyzed the first 10 individuals for this abstract. With respect to moving in free space, the results showed the following. Flexion and extension is an isolated movement in which only minimal lateroflexion or laterorotation take place (<5°). During laterorotation extension and contralateral lateroflexion occur towards the movement extremes (10-15°). For lateroflexion, we saw variable results in which in some individuals lateroflexion was paired with flexion and laterorotation and in other no noticeable other movements were made. With respect to the imposed movements, the results showed the following. For flexion and extension, moving the head support over a fixed point of rotation does not correspond with the movement of the head. At movement extremes, the head lost contact with the head support. Isolated laterorotation of the head support did not correspond well with the head movement, because lateroflexion of the head occurred also during this movement. For lateroflexion, moving the head support over a fixed point of rotation, the head lost contact with the head support at movement extremes. The combination of laterorotation and lateroflexion resulted in good match between the movements of the head support and the head itself with minimal movements over the flexion/extension axis (<5°). CONCLUSIONS: When moving the head with the use of a head support system, different axes should allow a certain degree of freedom to allow natural head movements. Furthermore, flexion and extension and lateroflexion should not be controlled over a fixed point of rotation. These results can quantify optimal movement paths to be implemented in the head support system.

R2-3: The influence of using the head-mounted display with modified web camera as left unilateral spatial neglect model on static and dynamic standing balance in the healthy subjects

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BACKGROUND AND AIM: Unilateral spatial neglect (USN) characterized by individuals with right hemisphere brain damage unable to respond and realize the contralateral side adequately. This condition causes the patient's visual attention to focus only on the non-paretic side. The correlation between impaired spatial orientations in neglect conditions with postural control balance still unclear, so that required to assess in more detail. The present study developed a model of left USN using a head-mounted display (HMD) with web camera modification in visual direction to the right. This study aimed to clarify the influence of using HMD with a modified web camera as a left USN model on static and dynamic standing balance in the healthy subjects. METHODS: Twenty-one healthy subjects (7 females, the mean age of 28.4 years, the bodyweight of 62.2 kg, and the height of 166.1 cm) participated in this study and gave written informed consent. The left USN model made by using a modified visual direction web camera on HMD of 10 degrees to the right. The static eyes opened and the bilateral dynamic standing balance test was evaluated by the COP monitor (SR Vision by Sumitomo Riko Co. Ltd) trough measure the COP length that indicates postural stability and the bilateral bodyweight load ratio that indicate postural orientation. The task instructed the subjects to keep their position for each test 30 seconds in the upright position as the Non-USN model and USN model condition. The paired t-test performed to calculate the comparison of use on each test condition. RESULTS: The results demonstrate that static standing balance changes (16.47%) significantly to unstable when the subjects perform as the

left USN model ($p<0.05$), in a condition of dynamic standing balance to the left incline (6.12%) more unstable than the right. The cross change occurred in the bilateral bodyweight load ratio in the course of the static eyes opened standing balance with two types of postural orientation response to the right and the left. While the bodyweight in the left and the right load ratio of the USN model tended to constant pressure in dynamic standing balance. In the observation, the alterations adjustment response in neck and trunk rotation also occurs as a form of postural adaptation. CONCLUSIONS: These results indicate that the left USN model experiences change for adjustment in postural adaptation on the static and dynamic standing balance due to deviations in the visual direction. KEYWORDS: head-mounted display, web camera, unilateral spatial neglect, standing balance, and healthy subjects.

R2-4: Effects of kinesthetic illusion induced by visual stimulation on the ankle joint for sit-to-stand in a hemiplegic stroke patient: AB single-case design

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[Introduction] During forwarding movement of the center of gravity (COG), including seat-off of sit-to-stand, hemiplegic stroke patients cannot move smoothly and become asymmetric. In healthy subjects, the anterior tibialis muscle (TA) is the earliest to activate at this time and its muscle activity is the largest. However, it has been reported that the sit-to-stand of hemiplegic patients involved reduced activity of the TA on the paralyzed side and increased muscle tone of the triceps surae (TS) on the paralyzed side. Therefore, smooth forward movement of the COG and load on the paralyzed lower limb are hindered by a decrease in the ankle dorsiflexion angle. These problems have been reported to be related to falls and must be improved in rehabilitation. Recently, the effects of kinesthetic illusion induced by visual stimulation (KiNvis) on ankle function in hemiplegic patients has been reported. KiNvis may induce kinesthetic illusion by observing movies and promote reciprocal activity of the muscles. However, there is no study on its influence on the sit-to-stand. Therefore, the purpose of this study was to investigate whether KiNvis on ankle function affects the sit-to-stand of hemiplegic patients using an AB design. [Subjects?Method] The subject was a 33-year-old man with left hemiplegia diagnosed with right putamen hemorrhage. The time since stroke was 133 days. The patient had lower Brunnstrom Recovery Stage IV and moderate sensory disorder. In the AB design, we conducted only conventional physiotherapy in phase A. In phase B, we conducted the same physiotherapy as in phase A, in addition to KiNvis for 5 minutes. Each phase lasted 5 days per week. Movies of non-paralyzed dorsiflexion of the ankle joint were recorded in a first-person view. In KiNvis intervention, the movies were flipped and positioned to maintain continuity in the affected ankle joint. The patient sat and watched the movies for 5 minutes. We evaluated the degree of kinesthetic illusion by visual analogue scale (VAS), voluntary dorsiflexion angle of the ankle joint, and Composite-Spasticity-Index (CSI) as muscle tone evaluation of the ankle plantar flexor on the paralyzed side. In addition, the dorsiflexion angle of the ankle joint on the paralyzed side during sit-to-stand, the weight-bearing symmetry values (WBSV) as asymmetry evaluation, and the sit-to-stand time were evaluated. We used the two standard deviation method for data analysis. [Results] In phase B, the degree of kinesthetic illusion was 83.6ą4.4 mm on average by VAS. Furthermore, automatic dorsiflexion angle of the ankle joint, CSI, the dorsiflexion angle during sit-to-stand, and WBSV were significantly improved compared with phase A. The sit-to-stand time was not significantly improved. [Conclusion] KiNvis had not effect on the sit-to-stand. However, KiNvis improves ankle function, and may affect the ankle dorsiflexion angle and asymmetry during sit-to-stand.

R2-5: EMG and accelerometery under different exoskeleton assistance modes in post-stroke gait rehabilitation

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BACKGROUND AND AIM: Early rehabilitation following stroke is paramount for the ability of stroke survivors to regain functional mobility. Recently, robotic rehabilitation methods have been developed to reduce the manual labour necessary from carers and to facilitate repeatable, over ground gait for the patients. The EKSO GT (Ekso Bionics Inc, Richmond, CA) offers various levels of assistance to users, including a maximum assist mode (MAM), where the robot drives motion in the lower limbs along a pre-programmed trajectory, and an adaptive assist mode (AAM), where the user is only assisted if the limbs deviate from the pre-programmed trajectory. However, it is not clear how these assistance modes alter gait parameters and EMG activity. METHODS: EMG (1925.93 Hz) and accelerometer (148.14 Hz) data were recorded from tibialis anterior (TA), soleus (SO), rectus femoris (RF) and semitendinosus (ST) muscles using wireless surface electrodes (TrignoŪ Delsys Inc) in stroke patients (n=9, age = 69.6 ą13.7 yrs) during gait in the exoskeleton. Stride, swing and stance times were identified from the accelerometer data, and maximum EMG amplitude (maxEMG), the integral of the EMG (iEMG) and the location of the maximum EMG were estimated for each muscle. Linear mixed effects models were employed to examine the effect of exoskeleton modes and side on each of the features. RESULTS: Swing times were significantly longer on the most affected side in MAM than in AAM ($p=0.01$). On the less affected side, both stride and swing times were significantly higher in MAM ($p=0.04, p<0.001$). In all muscles, maxEMG and iEMG were significantly higher on the less affected side than on the affected side ($p<0.001$). iEMG was significantly higher in AAM on the affected side in RF, SO and ST, while on the non-affected side, TA and SO were significantly more active in MAM. maxEMG was significantly greater in AAM for SO and ST on the affected side. On the less affected side, maxEMG was significantly higher for TA and SO in maximum assist mode. maxEMG occurred significantly later in gait cycle for RF and ST on both sides in MAM and later in the gait cycle for SO in AAM on the less affected side. CONCLUSIONS: The results of this study show that in both temporal gait characteristics and EMG features, there are significant differences between the more and less affected sides and the maximum and adaptive assist modes during gait in the EKSO GT exoskeleton for acute stroke patients. The results suggest that there is increased activation of RF, SO and ST on the affected side in AAM when compared with MAM. On the less affected side, there is increased activity in TA and SO in MAM, possibly due to restricted range of motion at the ankle joint in the exoskeleton.

Session Rehabilitation 3

R3-1: Motor control changes in people with recurrent neck pain

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BACKGROUND AND AIM: Low back and neck pain are the leading cause of disability worldwide, and each year neck pain is experienced by more than 350 million people [1]. These painful disorders are often characterized by periods of remission interrupted by new painful episodes. Neuromuscular adaptations have been reported in people with recurrent low back pain during an asymptomatic period, and findings support theoretical models of the interaction between movement and pain [2-4]. However, there is limited studies investigating neuromuscular function of people with recurrent neck pain. Therefore, this cross-sectional study aims to investigate whether neuromuscular changes are present in people with neck pain during a period of remission and whether features of neuromuscular control can discriminate this population from asymptomatic participants and people with chronic neck pain. METHODS: Forty-five participants were recruited consisting of 15 asymptomatic participants (6 men, age:31.1ą5.7 years), 15 participants with recurrent neck pain (5 men, age:35.2ą9.1), and 15 people with chronic neck pain (5 men, age:33.4ą9.3). Neck kinematics and sensorimotor features included range of motion, speed, smoothness of movement, and proprioception during active neck movements. Neck and trunk range of motion, variability of movement and cross-correlation were analysed during gait. Sternocleidomastoid and splenius capitis activity was recorded during the cranio-cervical flexion test, rapid arm movements, maximal and submaximal isometric contractions (flexion and extension). Perceived effort, fear of movement (TSK) and perceived health status(EQ-5D) were measured. Feature selection was conducted using the permutation importance for random forests [5]. The k-nearest neighbors (KNN) method using a repeated k-fold cross-validation was then adopted to assess the ability of the selected features to discriminate between different groups. RESULTS: Neck kinematics (speed and smoothness of movement) in flexion, extension, lateral flexion and psychological variables (TSK and EQ-5D) were able to discriminate asymptomatic participants from people with recurrent neck pain (Accuracy: 0.887, Sensitivity: 0.973, Specificity: 0.800) and people with chronic neck pain (Accuracy: 0.867, Sensitivity: 0.933, Specificity: 0.800). However, these features were not able to discriminate between the recurrent and chronic neck pain group (Accuracy: 0.613, Sensitivity: 0.640, Specificity: 0.587), and no other variables obtained an accuracy greater than 0.750 in this comparison. CONCLUSIONS: These results show that people with recurrent neck pain move differently compared to pain-free participants but similarly to people with chronic neck pain. Moreover, current pain symptoms did not affect the assessment; therefore, possibly a learning process influenced by fear of movement is involved, which could explain why some patients are more prone to develop repeated neck pain episodes. References: 1. Hurwitz EL, Randhawa K, Yu H, Côté P, Haldeman S. The Global Spine Care Initiative: a summary of the global burden of low back and neck pain studies. Eur Spine J. 2018;27(Suppl 6):796-801. 2. MacDonald D, Moseley GL, Hodges PW. Why do some patients keep hurting their back? Evidence of ongoing back muscle dysfunction during remission from recurrent back pain. Pain. 2009;142(3):183-188. 3. van Dieën JH, Flor H, Hodges PW. Low-Back Pain Patients Learn to Adapt Motor Behavior With Adverse Secondary Consequences. Exerc Sport Sci Rev. 2017;45(4):223-229 4. van Dieën JH, Reeves NP, Kawchuk G, van

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R3-2: The Scapular Kinematics and Muscle Activation in High School Baseball Pitchers with Glenohumeral Internal Rotation Deficit

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BACKGROUND AND AIM: Glenohumeral internal rotation deficit (GIRD) is believed to be a potential risk factor contributing to shoulder injury. Additionally, it is associated with altered scapular kinematics. However, it is unclear how these alterations are related to fastball pitching motions. The objective of the present study was to compare the scapular kinematics and muscle activity in asymptomatic baseball pitchers without GIRD (AswG), asymptomatic baseball pitchers with GIRD (AsG), and symptomatic baseball pitchers with GIRD (SG) during fast ball pitching. METHODS: Thirty-three high school baseball pitchers were recruited for three groups: AswG, AsG and SG groups. GIRD was defined as 20° less glenohumeral internal rotation in the dominant shoulder compared to the non-dominant shoulder. They underwent assessment of three-dimensional scapular kinematics (upward/downward rotation, anterior/posterior tilt, external/internal rotation)) and muscle activation (upper trapezius, lower trapezius, serratus anterior, anterior deltoid, biceps brachii and triceps brachii) during 6 trials of fastball pitching. RESULTS: For the scapular kinematics, anterior tilt was higher in the AsG and SG groups than in the AswG group (6.8-18.4° and 14.5°, p = 0.001-0.008 and 0.009, respectively). For the muscle activities, triceps brachii muscle activity was lower in the SG group than in the AsG group during the acceleration phase (37.8%, p = 0.016) and lower in the AswG group than in the AsG group during the early-cocking phase (9.9%, p = 0.015). In the serratus anterior muscle, muscle activity was lower in the SG group than in the AsG group during the early-cocking and late-cocking phases (4.8% and 30.2%, p = 0.004 and 0.007, respectively), and lower in the AswG group than in the AsG group during the late-cocking phase (30.8%, p = 0.006) CONCLUSIONS: Participants with GIRD had increased scapular anterior tilt during pitching. The enhanced muscle activation of the serratus anterior and triceps brachii may result from compensation for the deficit. In participants with symptomatic GIRD, the altered scapular kinematics was not intensified.

R3-3: Persons with patellofemoral pain exhibit higher levels of tensor fascia lata activity and lower levels of superior gluteus maximus activity during common therapeutic exercises.

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BACKGROUND AND AIM: Patellofemoral pain (PFP) is associated with excessive hip and femoral internal rotation and adduction in weight-bearing. [Powers 2017, 2010; Neal et al 2016] Hip muscles affecting these motions include tensor fascia lata (TFL), an abductor but also an internal rotator of the hip. It causes lateral displacement of the patella relative to the femur [Merican & Amis 2008/9; Kwak et al 2000] which can increase stress at lateral PF joint, common in persons with PFP. Gluteus medius (GMED) abducts the hip. Superior gluteus maximus (SUP-GMAX) abducts and externally rotates the hip. [Selkowitz et al 2016; Lyons et al 1983] Training these gluteal muscles is thought to assist in limiting excessive hip internal rotation (IR) and adduction, and lateral patellar displacement. Selkowitz et al [2013] identified exercises in which these gluteal muscles are more active than TFL in healthy persons. However, activity of these muscles has not been compared in persons with and without PFP in these exercises. Thus, the purpose of this study was to compare the magnitude of electromyographic (EMG) activity of TFL, GMED, and SUP-GMAX in persons with and without PFP. METHODS: Twelve subjects with and 20 without PFP participated. EMG signal amplitudes were obtained from the muscles described above using fine-wire electrodes. Maximum voluntary isometric contractions were performed to normalize each muscle's signal. Subjects performed quadruped hip extension with knee flexing and with the knee extended; clam and side-stepping, both with elastic resistance; and unilateral bridging; as recommended by Selkowitz et al. [2013] A 2-way ANOVA for each muscle compared EMG activity between groups across exercises. The alpha level was .05. Descriptive statistics such as gluteal-TFL activation (GTA) indexes and relative activation ratios (RARs), were calculated for each exercise to further compare muscles between and within groups. RESULTS: Across exercises, TFL activity was significantly greater, and SUP-GMAX significantly lower, for the PFP group versus the control group. There was no significant difference between groups for GMED activity. In the control group, the gluteal muscles demonstrated greater activity than TFL in all statistical tests in all exercises. In the PFP group, only the clam produced higher activity of the gluteals compared to TFL in all statistical tests; the side-step had marginally favorable results; the other exercises failed to activate the gluteals more than TFL. CONCLUSIONS: Overall, persons with PFP had difficulty activating the gluteals more than TFL compared to those without PFP in selected therapeutic exercises. This is consistent with studies that have found increased hip internal rotation and lateral patellofemoral stress in persons with PFP. However, in the PFP group, the clam exercise still activated both gluteals better than TFL. Thus, the clam would be an appropriate exercise to prescribe for persons with PFP.

R3-4: Activation of hip muscles during a step-down task in persons with and without patellofemoral pain.

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BACKGROUND AND AIM: Decreased hip muscle performance is associated with patellofemoral pain (PFP). [Powers et al 2017] The step-down task is commonly used in clinical practice to assess and train patients' muscular control of "medial collapse" (excessive hip internal rotation and adduction in weight-bearing) in patients with PFP. [Neal et al 2016; Powers 2010] Both excessive hip adduction and internal rotation have been found to predict self-reported pain and function during a step-down. [Nakagawa et al 2013] Several hip muscles are thought to impact medial collapse. The tensor fascia latae (TFL) abducts but internally rotates the hip/femur and causes the patella to move laterally on the femur. [Kwak et al 2000; Merican & Amis 2008, 2009] The gluteus medius (GMED) abducts the hip; the superior gluteus maximus (SUP-GMAX) abducts and externally rotates (in addition to extending) the hip. [Selkowitz et al 2016; Lyons et al 1983] The electromyographic (EMG) activity of these muscles has not been compared between persons with and without PFP during the step-down. Given the importance of these muscles in hip kinematics and PFP, the purpose of this study was to compare the activation of TFL, GMED, and SUP-GMAX in persons with and without PFP during a step-down. METHODS: Twelve persons with and 12 without PFP participated in this study. Fine-wire electrodes were inserted into the above-described muscles. Maximum voluntary isometric contractions were performed to normalize each muscle's signal during the step-down. A metronome was used to standardize the pace. Independent t-tests were used to compare the differences between groups for each muscle. In addition, 1-way repeated measures ANOVAs were performed to compare EMG activity of the gluteal muscles to TFL within each group. The alpha level was .05. Relative activation ratios (RARs) of each gluteal muscle to the TFL, and gluteal-to-TFL activation (GTA) indexes, were calculated for each group and compared descriptively within and between groups. RESULTS: GMED was significantly less active in persons with PFP compared to those without PFP. There was no significant difference between groups for TFL and SUP-GMAX activity. Within-groups analyses showed that neither group demonstrated greater activation of the gluteals compared to TFL. In fact, the TFL exhibited greater activity than SUP-GMAX in the control group; and greater activity than both gluteals in the PFP group. The RARs of the gluteals in both groups were at or less than 100%, and the GTA indexes were less than 20. CONCLUSION: Both groups failed to demonstrate that the gluteal muscles had greater activation than the TFL during the step-down. Persons with PFP were worse than the control group. It is unclear how the deficits relate to motor control or strength, and cause or effect of PFP. Persons with and without PFP may benefit from training performance of the step-down and using exercises that activate the gluteals better than TFL.

Sensing/Sensors/AI/IoT 1

S1-1: The Consensus for Experimental Design in Electromyography (CEDE) project

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BACKGROUND AND AIM: Electromyography (EMG) provides an opportunity to discover phenomena associated with muscle activation and can address many important questions of sensorimotor function, but requires careful consideration of experimental design. Quality of EMG recordings and validity of interpretation of signals depends on many features that extend from the selection of electrodes to the signal processing and interpretation of the derived measures. Selection of the ideal experimental design is paramount, yet can be difficult. Suboptimal selection of methods compromises the validity of the experimental outcome. A key issue is that methods that are appropriate for some applications may not be appropriate for others. Further, many design features do not have black-and-white recommendations and instead, most require consideration of pros and cons with selection of a design

that is most appropriate for the specific application. The Consensus for Experimental Design in Electromyography (CEDE) project is an international initiative which aims to guide decision-making in recording, analysis, and interpretation of EMG across all applications including surface and invasive/intra-muscular methods. The major output of the project is the development of a series of matrices to provide guidance for planning and interpretation of EMG methods using a Delphi consensus process. Each matrix is designed to provide recommendations and detailed justification such that the user is fully informed. METHODS AND RESULTS: The CEDE project involves and expert group (n=21) who were selected according to track record of expertise in EMG methodology and leadership in EMG. The topics to be addressed by individual matrices developed by the CEDE project team was selected using a Delphi process. Topics with approval of at least 70% of respondents were retained. The agreed process for development of EMG experimental design matrices involves steps of consultation, expert input and consensus. For each design matrix a steering committee (early career researcher and 2-3 additional content experts) is established to develop the initial draft matrix. Feedback is sought from the CEDE team and incorporated. The matrix is subjected to 1-3 rounds of a Delphi process to reach consensus. CEDE members rank acceptability of content, and provide comments. Completion of this process is considered as endorsement of the final matrix. A checklist is prepared that highlights key issues to considered when planning EMG recordings. The final matrices are accompanied by a brief report and published as papers in the Journal of Electromyography and Kinesiology (e.g. 1). CONCLUSIONS: The matrices developed by the CEDE project will aid in the maintenance of high standards of EMG recording, analysis and interpretation. It is designed for use by researchers (new and experienced), ideally during the planning of an experiment using EMG, reviewers and editors, and users of research (clinicians and researchers). Matrices provide; consensus opinion based on current knowledge, rationale for each recommendation, clear indication if a choice/option is inappropriate, and recommendation of what limitations should be reported when no ideal solution is available. A limitation is that new technologies, analyses and understandings will evolve after the publication of the matrices. Matrices are not intended to replace formal training in EMG, but provide a useful reference, based on consensus opinion of experts in the field, to ensure all issues are considered when developing and interpreting EMG recordings/data.
REFERENCES: 1. Besomi, M., Hodges, P. W., Van Dieen, J., Carson, R. G., Clancy, E. A., Disselhorst-Klug, C., . . . Wrigley, T. (2019). Consensus for experimental design in electromyography (CEDE) project: Electrode selection matrix. J Electromyogr Kinesiol, 48, 128-144.

S1-2: A Wearable and Modular System for Neuromuscular System Assessment

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BACKGROUND AND AIM: In the last decades, neuromuscular disorders and pathologies have been in the forefront of the main causes of functional impairments in industrialized countries. Wearable sensors and actuators, specifically designed for the assessment and training of the neuromuscular system in both healthy and pathological subjects are today preferred over bench systems in clinical, research or tele-medicine contexts. So far, however, none of the wearable systems available meets the architectural demands necessary for the detection of electromyograms (sEMG) with pairs or grids of electrodes, for the collection of biomechanical data and for issuing of stimulation pulses. The aim of this study was to design, develop and test a modular, wireless, and customizable system, inheriting in a single device all technical features required by different applications, from single motor unit study to functional electrical stimulation. METHODS: The system architecture (Figure) consists of four wireless, modular and miniaturized sub-systems allowing to: i) acquire biomechanical variables; ii) detect bipolar sEMG signals; iii) detect High-Density sEMG signals, and iv) deliver current pulses by means of surface electrodes. All modules composing the system (Sensor/Stimulation Units) communicate with a Processing Unit (mobile device PC) and can be worn by the subject, creating a Body Area Network (BAN). RESULTS: The design of bipolar sEMG and biomechanical sub-systems was addressed in parallel, allowing to sample a combination of two bipolar sEMG signals, raw analog or conditioned analog signals, or inertial signals coming from an integrated IMU. The HD-sEMG Sensor Unit allows for the acquisition of 32 monopolar sEMG signals detected by means of 1D or 2D electrode arrays. The high miniaturization of the electronic circuit, combined with the absence of connecting cables between the detection and acquisition systems, ensures a high rejection to movement artefacts commonly affecting HD-sEMG signals during dynamic tasks. The Stimulation Unit allows to: i) program a custom stimulation pattern in terms of waveform and timing; ii) trigger the stimulation start/stop through signals detected by means of different Sensor Units. A multi-platform software, running on the Processing Unit, for the acquisition, processing and visualization of signals from the Sensor Units was designed and implemented. The software architecture was designed to be easily expandable through custom plugins developed for ad-hoc applications. CONCLUSION: The system described here has been proven to be highly versatile, being successfully used in several scenarios. The HD-sEMG Sensor Units were used during highly dynamic tasks to emphasize the system wearability and robustness to movement artefacts. The bipolar sEMG and HD-sEMG Sensor Units were used in an Augmented Reality biofeedback for the monitoring of the muscular activity. Two electrical stimulator modules were tested in combination with the biomechanical Sensor Unit in a closed-loop FES-Cycling application. The developed system can be considered as an enabling technology, allowing to design new applications for the neuromuscular system assessment and motor rehabilitation.

S1-3: Seniam; what has it delivered and what can we learn from it

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In the late 90's, surface EMG became rapidly popular, resulting in a broad field of applications, involving neurology, rehabilitation, orthopedics, ergonomics and sports. However, at that time, most developments took place scattered over the world in specific scientific groups, using rather different methodology. As a consequence when one considers applications, exchange and compilation of data from different groups was difficult. Another consequence was that due to a lack of standardisation, industrial activity at a European scale was missing. This situation was the key reason to develop and start the European concerted action SENIAM: Surface EMG for Non-Invasive Assessment of Muscle. The objectives of SENIAM (1997-2000) were: 1. To enhance European collaboration and exchange of knowledge on surface EMG 2. To solve key items that prevented a useful exchange of data and clinical experience. This concerned especially the development of recommendations for: - Sensors (configuration of electrodes), and sensor placement procedures, - SEMG signal processing - SEMG modeling. The core working group consisted of: H.Hermens, C.Disselhorst-Klug, B.Freriks, G.Rau, R.Merletti, D.Farina, D.Stegeman. During the SENIAM project 4 general workshops and 3 topical workshops have been organised. On average about 40 people participated in each general and 15 in each topical workshop. The proceedings all have been published, resulting in 7 books, addressing all these aspects. The recommendations on SEMG recording and processing have been published in a separate book (SENIAM 8) as well as on a CD-ROM (SENIAM 9). The Seniam paper in JEK has been cited over 4000 times, the book with the recommendations over 2000 times. The books have also been distributed quite extensively over the world, especially the Seniam 8 book over 2500 times. So, one can conclude that Seniam was a very successful project with a high impact for the widespread application and exchange of knowledge and experience of surface EMG. An analysis shows that especially scientists and clinicians who want to use the EMG for their clinical research questions, are by far the biggest users. Meanwhile, science has progressed of course, including the knowledge on placement of electrodes and including the use of array electrodes, and processing the EMG signals. It is great to see that by joined efforts, progress is being made, like reflected in the "Consensus for experimental design in electromyography (CEDE) project: Electrode selection matrix" by Besomi, Hodges and many collaborators

S1-4: Deep Neural Networks for the Automatic Classification and Segmentation of Athletic Movement Tasks

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BACKGROUND AND AIM: Movement screens are used to assess the overall movement quality of an athlete in order to predict injury risk and identify performance deficits that can be targeted in training. Typically, the athlete will perform a series of movements while a trained rater visually observes and scores the movements. While inter-and intra-rater reliability for movement screens are good, inter-rater reliability for subtest components can be poor and dependent on rater experience. Furthermore, concerns have been raised that grading criteria can be ambiguous and scores may not be sensitive enough to detect movement abnormalities. Recently our lab group has developed objective scoring methods for movement screens. Such data-driven approaches have the potential to improve the repeatability of scoring and increase the ability to detect subtle differences in movement patterns. However, these currently use optical motion capture and require manual pre-processing of data to identify the start and end points of each movement. Therefore, in this work, we aimed to use deep learning techniques to automatically identify and segment movements typically found in movement screens and assess the feasibility of doing so based on wearable sensor data. METHODS: Motion capture data were collected on 417 athletes ranging in skill level from recreational to professional (e.g. playing in the NBA, MLB, PGA, etc.) by Motus Global (Rockville Center, NY). Each athlete performed 13 athletic movements known to challenge whole-body mobility and stability: hop down right/left, bird-dog right/left, drop jump, T-balance right/left, step-down right/left, L-hop right/left, and lunge right/left. With these data we trained a deep neural network (DNN) architecture that combines convolutional and recurrent layers to automatically classify and segment the movement tasks on a subset of 278 athletes in PyTorch. A validation subset of 69 athletes was used to tune the hyper-parameters and the final network was tested on the remaining 70 athletes. Simulated inertial measurement unit data (i.e.

Euclidean norm of segment linear acceleration and angular velocity, as well as segment orientation) were generated based on the optical data and the network was trained on this data for different combinations of body segments. RESULTS: Classification accuracy, assessed using the micro-averaged F1 score - the harmonic mean of precision and recall, was similar for DNNs trained using the optical and full-body simulated inertial measurement unit data at 90.1 and 90.2%, respectively (Figure 1). A good classification accuracy of 85.9% was obtained using as few as three simulated sensors placed on the torso and shanks. However, using three simulated sensors on the torso and upper arms or fewer than three sensors resulted in poor accuracy (<70%). These results for simulated sensor data indicate the feasibility of classifying athletic movements using a small number of wearable sensors placed on key segments. CONCLUSIONS: This work could facilitate objective data-driven methods that automatically segment and score overall movement quality using wearable sensors to be easily implemented in the field.

S1-5: Feature selection for motor intent recognition using evolutionary algorithms

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Choosing the right features is important to optimize myoelectric control systems, such as in prosthetic control. EMG signals are noisy in nature, which makes it more challenging to extract useful information[1]. In literature, most commonly used features are the so-called Hudgins-features[2] with auto-regressive coefficients (H+AR)[3], although it is not clear if those are the most optimal features and multiple other features exist[1]. Hence, it is important to explore whether there is a more optimal feature set, to enhance myoelectric control. To cope with high dimensional data, i.e. many possible feature extraction methods, evolution based algorithms can be used to find optimal solutions[4]. Therefore, the goal of this research is to employ a meta-heuristic search method, in this case a genetic algorithm, for feature selection to enhance motor intent recognition performance compared with using the H+AR features. The genetic algorithm uses "chromosomes" and each chromosome consisted of "genes". These genes represent which data channel is used, what kind of window sizes are extracted and what type of features are extracted per data channel. Using mutation and cross-over events, a population of chromosomes is optimized to result in the highest performance. Eight able bodied subjects (6m, 2f) participated in this study. Kinematics of the right leg and EMG of 8 leg muscles were collected using Xsens MVN link and Delsys Trigno respectively. Subjects performed different activities including sitting, standing, walking, stair ascent/descent, ramp ascent/descent. Additionally data from 10 subjects from the ENABL3S dataset[5] were used as well. The classifier to determine performance was based on the work of Hu et al[3]. The genetic algorithm used EMG, IMU and joint angle data and 55 possible feature extraction methods. The resulting overall error rate (mean ą SEM) was 4.56% ą 0.52 versus 3.85% ą 0.47 ($p<0.0001$) for H+AR features and optimized features respectively. Steady-state performance was 2.65% ą 0.40 versus 2.56% ą 0.39 ($p=0.1378$) and transitional performance was 14.65% ą 1.57 versus 10.08% ą 1.11 ($p<0.0001$). Using a genetic algorithm for feature selection could greatly decrease transitional errors in motor intent recognition and decrease overall error. Although the H+AR features are commonly used due to their simplicity, these result show the opportunity to choose better feature combinations. Using genetic algorithms, an optimal feature set can be found relatively fast without the need to try out every possible combination. This optimization strategy can be used to determine optimal feature sets for motor intent recognition to be used prosthetic control. [1] Phinyomark et al, Journal of the Royal Society Interface, 2017 [2] Hudgins et al, IEEE Transactionson Biomedical Engineering, 1993 [3] Hu et al, Frontiers in Robotics and AI, 2018 Jun [4] Diao & Shen, Artificial Intelligence Review, 2015 [5] Hu et al, Frontiers in Robotics and AI, 2018 Feb

Session Motor Units 1

U1-1: Serial motor unit decomposition and high-density surface electromyography in amyotrophic lateral sclerosis

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BACKGROUND AND AIM: Amyotrophic lateral sclerosis (ALS) is a devastating progressive neurodegenerative disorder of upper and lower motor neurons with a median survival of just 3 years from symptom onset. The early events that lead to cell dysfunction and death in ALS have not been fully characterised. Due to its enhanced tolerability amongst patients, we have been employing non-invasive, high-density surface EMG (HDSEMG) in longitudinal studies of ALS patients. In this study we aimed to characterise both voluntary and ectopic patterns of motor unit (MU) firing at different stages of disease. We hoped that this might lead to a better understanding of varying vulnerability of MU subtypes in ALS and ultimately to a potential new biomarker of disease for use in clinical trials. METHODS: Twenty patients with ALS and five patients with benign fasciculation syndrome (BFS) were recruited from King's College Hospital Motor Nerve Clinic (London, UK) between July 2017 - Feb 2019. Each patient underwent up to seven assessments at intervals of two months. Baseline demographic data, a neurological examination and clinical narrative were documented on initial attendance. Additionally, five healthy controls (HC) underwent a single assessment. For each HDSEMG measurement, 30 minutes of resting muscle and 1 minute of light voluntary activity were taken from biceps brachii bilaterally. The FastICA Peel-off technique was employed in MATLAB to decompose 10-30s segments of HDSEMG data. Recordings were grouped into: a) ALS-Strong, b) ALS-Weak, c) BFS, and d) HC. Linear mixed-effect regression (LMER) models were employed in R to account for the pseudoreplication of serial measurements. RESULTS: In total, 303 MUs (ALS-Strong = 85 MUs, ALS-Weak = 111, BFS = 79, HC = 28) were identified from 28 individuals (ALS: n=18, BFS: n=5, HC: n=5). The median (inter-quartile range) MU numbers identified per recording were: ALS-Strong = 3 (3), ALS-Weak = 3 (1.8), BFS = 3 (2) and HC = 3.5 (3.5). Excluding motor units with fewer than 40 potentials, intergroup comparison (LMER model) found mean MU inter-spike interval (ISI) to be lower in ALS-Weak muscles (mean ISI = 84.5ms) than in ALS-Strong muscles (mean ISI = 99.7ms; $p < 0.05$), with no difference between all other groups (see figure). Combined resting and light voluntary longitudinal recordings from 15 ALS patients identified three distinct patterns of MU firing: MU 1 - produced only fasciculations (most indicative of fast/intermediate MUs); MU 2 -produced fasciculations and was active during light voluntary contraction (most indicative of hyperexcitable, slow MUs); MU 3 - was only active during light voluntary contractions (most indicative of a normal, slow MU). Pattern 2 of MU firing was most prevalent in ALS muscles that became weak during the 12 months of follow-up, hinting that the increased fasciculation frequency in this group may be due to ectopic activity in the first-recruited, slow MUs. CONCLUSIONS: This study demonstrated a reduced ISI of MU firing during light voluntary contraction in weak ALS muscles compared to strong ALS muscles. This corresponds to an increased firing frequency that may indicate the hyperexcitability of the first-recruited, slow MUs. This finding may also represent a compensatory mechanism in the face of a shrinking MU pool as ALS progresses. Previous studies in mice have demonstrated that slow MUs are initially spared in the disease course, while fast and intermediate MUs are more vulnerable to disease. This study highlights the potential for HDSEMG and MU decomposition to dissect out the activity of a spectrum of MU subtypes. This technique could feasibly be conducted in the patient's home, as it is non-invasive and requires no electrical stimulation. The increased accessibility of a home-based approach would make it an appealing option in clinical drug trials.

U1-2: Alpha-motor neuron adaptations to trans-spinal direct current stimulation after incomplete spinal cord injury

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BACKGROUND AND AIM: Over the past decade, growing interest has focused on trans-spinal direct current stimulation (tsDCS) as a non-invasive approach to restore neuromuscular function after neurological impairment (e.g. spinal cord injury). Although current modelling and perturbation-based experimental methods provide global information on how tsDCS modulates corticospinal excitability, they do not provide insight on how individual alpha-motor neurons respond to electrical fields. This is a major element hindering the development of neuro-modulative technologies highly tailored to an individual patient. In this context, we propose a novel signal-based strategy for interfacing with spinal cord alpha motor neurons in spinal cord injury patients before-and-after undergoing tsDCS. METHODS: Four incomplete spinal cord injured patients performed isometric plantar flexion sub-maximal contractions at three different force levels. This was done before, immediately after and 30-minute after cathodal and sham (control) stimulation. We recorded high-density electromyography (HD-EMG) from the soleus and gastrocnemius muscles, and employed convolutive blind source separation to decompose the recorded signals into alpha-MNs discharges across multiple lumbosacral segments. Due to the presence of external noise (i.e. real-world clinical scenario), errors in the estimation of individual spike trains were inherently present. To counteract this limitation, we first developed an algorithm to assess the quality of the decomposed motor neuron spike trains and to remove those with poor quality. To this end, we computed three quality metrics: pulse-to-noise ratio, coefficient of variation of inter-spike intervals and z-transformed correlation coefficients between the force and the estimated neural drive to the muscle (low-pass filtered cumulative spike train). Secondly, we computed interspike train coherence to estimate the strength of common synaptic input and whether this modulated in response to tsDCS. We conducted our experiments with a double-blind sham-controlled design and subsequently compared the results with a series of tests providing a solid basis for validation. RESULTS: For the quality algorithm, the maximum likelihood of the correlation distribution increased after quality selection from $z = 0.58$ to $z = 0.72$ for the soleus, and from $z = 0.58$ to $z = 0.60$ for the gastrocnemius. The coherence

areas and peaks showed a consistent decrease in the delta band (< 5 Hz) after tsDCS with respect to the pre-stimulation condition (areas: $p < 0.05$ and peaks: $p < 0.1$). CONCLUSIONS: The positive shift of the correlation distribution indicates that no relevant neuro-mechanical information was lost after quality selection. Coherence analyses suggest that the strength of common synaptic input is modulated in response to electrical stimulation. This has multiple implications for understanding altered motor function after peripheral neuromuscular injuries and will open up new avenues for the development of closed-loop neuro-modulation techniques.

U1-3: Limits of decomposing single motor unit action potentials from the entire masseter muscle obtained by high-density surface EMG

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Introduction: Motor unit (MU) recordings from the masseter muscle are confronted with its task-dependent heterogenous activation and the muscle's anatomical complexity (Schindler et al. 2014). Published data at a MU level are either based on locally restricted measurements or do not consider a wider activity level (Lapatki et al. 2019). Goals of this study were to systematically collect data on MU amplitude distributions over the muscle, and to explore the maximum possible activity range which is still decomposable from high-density surface EMG recordings. Methods: A thin and flexible high-density surface EMG grid (256 channels) with 3-mm inter-electrode-distances was positioned over the right masseter muscle in 7 volunteers (age: 24 - 29 yrs., 1 female, 6 males). Subjects were trained to perform a series of ramp and hold contractions at different levels (5-50% of the maximum voluntary contraction (MVC)). Bite force was monitored using an intraoral 2D force transducer. Signals were decomposed using the Convolution Kernel Compensation (CKC) method (Holobar & Zazula 2007). Automatically decomposed MU action potential trains were manually edited for optimizing decomposition results. Results: The average number of identified MUs was 8.9 ą 5.2 for the 5% MVC contraction level. This number increased to 13.3 ą 4.7 MUs for contraction levels between 30-50% of MVC. Decomposition results from higher activity levels tended to increase the merging of MUs in the automatic CKC decomposition. More specifically, at 5% MVC, 59.2% of the MUs decomposed by CKC were judged to be well decomposed individual MUs, 21.6% were merged but could be separated by manual editing, and 19.2% of the merged MUs could not be separated. At 20% MVC corresponding percentages were 48.7%, 23.0% and 28.2%, respectively. Discussion: Due to the coverage of the entire masseter we were able to decompose MU activity reflecting the muscle's complete surface topography. Higher contraction levels lead to an increase of the number of decomposed MUs, but also increase the risk for merging of MUs in the automatic decomposition. Merging may be explained by very similar surface topographies of distinct MUs. Hence, further strategies have to be developed to enhance surface EMG-based MU analysis in the masseter muscle, particularly at moderate to submaximal contraction levels.

U1-5: Template matching algorithm for identification and tracking of motor units using surface EMG arrays

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BACKGROUND AND AIM: Surface EMG decomposition enables the noninvasive detection of a relatively large number of concurrently active motor units. However, it can be difficult to reliably track the activity of the same motor unit across different trials when compared with traditional intramuscular recordings. Furthermore, acceptance criteria for determining the reliability of decomposed data often rely on metrics of waveform stability or similarity when comparing motor unit action potentials (MUAPs) within a trial which can be difficult to quantify. To address this, a new method for comparing MUAP waveforms within and across trials is proposed. The method is based on analysis of MUAP waveforms in multi-dimensional space and provides a more accurate assessment of waveform similarity when compared with correlation analysis. METHODS: Surface EMG signals from four adjacent bipolar electrode pairs were simulated using a model of the motoneuron pool and MUAPs generated from an anatomically accurate model of the first dorsal interosseous muscle [1]. The underlying action potential waveform was estimated for each motor unit using a novel method incorporating information from all four electrodes. Instantaneous MUAPs corresponding to each firing instance of a motor unit were extracted and reduced in 4-dimensional (4-D) space to generate a representative MUAP template for that motor unit. Similarity between pairs of MUAP templates was assessed by comparing 4-D trajectories for these motor units. Duplicate MUAP templates were introduced to the pool of simulated motor units, with modifications to conduction velocity, noise level and amplitude, to test the accuracy of the algorithm in identifying waveforms from the same motor unit. RESULTS: MUAP templates obtained using the proposed method yielded a more accurate representation of the underlying MUAP (generated using the EMG model) than templates obtained using spike-triggered averaging [2]. Analysis of the motor unit action potential waveforms in 4-D space was able to accurately identify all duplicate MUAPs introduced into the simulated motor unit dataset, without classifying any distinct MUAPs as a match. By comparison, cross-correlation (CC) analysis applied to the same dataset indicated that 6.6% of MUAP pairs had a CC>0.9, though only 1.1% of all pairs were duplicate MUAP waveforms. CONCLUSIONS: A new method for extracting and comparing MUAP waveforms from decomposed surface EMG is proposed. It enables multidimensional action potential trajectories to be estimated for each identified motor unit and quantitative assessment of the similarity between MUAP trajectories. The algorithms can be used to detect similar or unstable MUAP waveforms within a trial, to assess the accuracy of data obtained through EMG decomposition and to reliably track the same motor unit across different trials.
[1] Pereira Botelho et al. (2019). PLoS Comput. Biol.,15(8),e1007267. [2] Hu et al. (2013). J Neurophysiol,110(5),1205-1220.

SYMPOSIUM ABSTRACTS

Symposium 1: Neuromuscular adaptation to pain during movement

S1-1: Patterned change in EMG activity in response to phasic pain during gait.

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BACKGROUND AND AIM: Pain induces changes in the planning and execution of movements. These changes bring short-term relief (decreased exposure to pain) but are thought to contribute to the chronicization of pain in the long term. To study this theory, a better understanding of the physiological basis of movement adaptation to pain is needed. To this end, several challenges must be overcome, including the development of a pain paradigm that induces a pattern of adaptation that is reproducible across individuals. Thus, the objectives of this study were to: 1) develop an experimental pain paradigm that induces a systematic, patterned change in muscle activity during gait; 2) verify to what extent stimulus characteristics influence this adaptation; 3) evaluate the persistence of the adaptation in catch trials. Our hypotheses were that: 1) phasic pain triggered at heel contact would modify lower limb muscle activity during gait; 2) these patterned changes would differ for a phasic pain relieved by heel off (controllable) versus a fixed duration of 300 ms (uncontrollable); 3) adaptations to pain would persist during catch trials. METHODS: Repeated trains of electrical stimulation (pain rating: 4/10) were administered to the right malleolus of healthy subjects during treadmill gait at 4 km/h. EMG activity was recorded from both flexor and extensor muscles contributing to gait. Root-mean-square amplitude (RMS) was measured during five successive bouts (i.e. conditions) of treadmill walking: Baseline (5 min), Pain 1 (3 min), Washout 1(5 min), Pain 2 (3 min) and Washout 2 (5 min). Pain conditions, controllable and uncontrollable, were randomized. Five catch trials (pain was expected, but absent) were presented every 30 steps during pain conditions. Participants were unaware of the difference between conditions. Differences between RMS amplitude between conditions were assessed using a repeated measures ANOVA. Significant effects were identified using Tuckey's post hoc analyses. RESULTS: A systematic, patterned change in muscle activity was observed during pain conditions compared to Baseline and Washout 1. Compared to Baseline, the ipsilateral tibialis anterior activity burst before heel contact was reduced during both controllable and uncontrollable pain conditions ($p < 0.001$) and was recovered during Washout 1 ($p < 0.001$). The decreased TA activity burst was also observed during catch trials. However, there was no difference in pattern changes across pain conditions ($p = 0.48$). CONCLUSIONS: This new model of phasic pain triggered by heel contact efficiently induces systematic, patterned changes in muscle activity, regardless of stimulus controllability. Based on catch trial analysis, these patterned changes have a strong central component and a rapid onset. This model therefore has interesting potential to study the central contributors to movement adaptation to pain.

S1-2: Task-relevant experimental pain using low-frequency sinusoidal electrical stimulation

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BACKGROUND AND AIM: According to contemporary pain adaptation theories, changes in the way we move are a purposeful adaptation to decrease pain (1). Most available experimental pain models, however, do not offer the possibility to modulate pain intensity according to how individuals move. For instance, hypertonic saline solution injections induce pain of a constant intensity, regardless of how a person moves. Delayed onset muscle soreness and nerve growth factor induce muscle pain of variable intensity and duration that is only modulated by muscle stretch/contraction. Although electrical stimuli provide a way to carefully control pain duration, timing and intensity, the use of electrical stimuli for investigating motor adaptation to pain is limited by habituation to the stimuli and by stimulation artefacts in the electromyographic (EMG) signal. We investigated whether sinusoidal electrical stimuli can be used to induce pain with minimal habituation or artefacts in the EMG signals, and to induce task-relevant pain, where pain intensity depends on a person's motor behaviour. METHODS: Fourteen participants received painful electrical stimuli (sinusoidal: 4, 10, 20 and 50Hz; and traditional square waveforms 1ms long: 40Hz) delivered using surface electrodes placed on the skin above the infrapatellar fat pad of the right knee. The amplitude of the electrical stimuli was either constant to test habituation over a 60s time period, or modulated in real-time to alter perceived pain intensity based on the vertical force applied by the participant's right leg on the ground to induce task-relevant pain during standing. EMG signals were collected from the right vastus medialis. RESULTS: Habituation of pain ratings was observed for electrical stimuli applied as square waves and sinusoidal waveforms at 50 Hz ($p<0.001$), but not for lower frequency sinusoid. Conventional high-pass EMG filtering removed the stimulation artefact for 4Hz and 10Hz stimuli, but not when square wave stimuli were used. During the quiet standing task, participants progressively unloaded the right leg (to which the electrical stimuli were applied) over time ($p<0.01$) when aware that there was a way for them to modulate their perceived pain intensity. Also, their perceived pain intensity at the end of the trial correlated with the weight applied by the right leg on the ground (R2=0.65), demonstrating task-relevant changes in perceived pain intensity. CONCLUSIONS: Our results show that low-frequency sinusoidal stimulation is a promising experimental pain model to induce tonic or task-relevant knee pain without artefacts on the EMG signals. The association between motor adaptation and reported pain intensity supports the use of this novel experimental model to test motor adaptation to task-relevant pain. The possibility for individuals to experience less pain by changing the way they move may help us gain a better understanding of how pain and movement influence each other. 1. Hodges & Tucker, PAIN, 2011.

S1-3: Influence of low back pain on trunk motor control and pain modulation following exercises

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Low back pain (LBP) influences the way people moves their spine. Several studies identified alteration in the control of trunk muscles in LBP. It has been suggested that this alteration is due to a reorganisation of the regions of the central nervous system (CNS) involved in motor control. The first part of this presentation will review the latest evidence on the impact of LBP on the organisation and the function of the motor-related areas in the CNS. The focus of the presentation will be directed on studies using neurophysiological techniques such as transcranial magnetic stimulation (TMS) and afferent stimulation (e.g. noxious electrical stimulation). Many studies observed a different function or organisation of motor-related CNS areas in LBP (e.g. primary motor cortex) even though important discrepancies between studies are present. Evidence suggest that some individuals with LBP, but not all, may present with a reorganization of the motor areas within the CNS suggesting the importance of subgrouping. The second part of the presentation will focus on the influence of movement on pain sensitivity. For example, exercises as endorsed by clinical guideline as an efficient intervention to treat LBP. Exercise-induced hypoalgesia (EIH) represents a decrease in pain sensitivity following different types of exercises (e.g. aerobic, isometric contraction) and one potential mechanism by which pain may be reduced following exercises. EIH is produced by the activation of central nervous areas involved in the control of pain. Some authors suggest that individuals with LBP has a reduction of the global efficacy of the pain control systems. This part of the presentation will review the evidence on the impact of LBP on pain modulation following exercises. Some studies observed that individuals with LBP present a sensitisation (or a lack of hypoalgesia) of the low back area following back-related movements/exercises. However, current literature does not support a general alteration in pain control since sensitisation following exercises is usually only related to the painful low back area. We will also argue that different subgroups of individuals with LBP may respond differently to exercises.

S1-4: Balancing muscle force in adolescent patellofemoral pain

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BACKGROUND AND AIMS: Idiopathic patellofemoral pain (PFP) is the most common cause of knee pain in female adolescents, affecting 14-21% of this population. Breaking from an earlier theory that adolescent PFP was solely an overuse injury, recent evidence suggests that adolescent PFP etiology may related to knee joint dynamics. A leading model for the etiology of adult PFP is that altered force distribution between the vastus lateralis (VL) and vastus medialis (VM) may alter patellofemoral kinematics, leading to suboptimal joint loading and pain. In adults, electromyography is regularly used to quantify activation of VL and VM. However, muscle activation alone cannot provide information on the distribution of muscle force. Rather, the force a muscle produces depends on its activation and various mechanical characteristics (e.g., physiological cross-sectional area (PCSA), force-length and force-velocity properties, specific tension). Importantly, during isometric contractions, the difference in force-generating capacity between VL and VM is mainly attributable to their difference in PCSA. Further, the muscles moment arm will influence its effective force. Although altered kinematics have been demonstrated in adolescents with PFP, no data are available on the distribution of VL/VM force in this cohort. We aimed to determine if the VL/VM force distribution and their moment arms, relative to the patella, differ in adolescents with PFP compared to pain-free adolescents during isometric tasks. METHODS: Twenty adolescents with PFP and 20 age, sex, activity & BMI matched controls (15±2 years, 18 girls, 45.8±7.7 MET-24, 21.2±3.2 kg/m^2) participated. Muscle activation was recorded during isometric knee extensions (10, 20 and 40% maximal voluntary contraction (MVC), knee at 60°) and wall squats (knee at 60°), and normalised to that obtained during MVCs. We used ultrasound to determined fascicle length and pennation angle (participant seated at rest, knee at 60°). Muscle volume and moment arm were calculated from magnetic resonance images (participant prone at rest, knee at ~60°). PCSA was determined from muscle volume/fascicle length. Muscle Force was determined as PCSA*cosine (pennation angle)*muscle activation. RESULTS: There were no significantly different between group outcomes during any tasks, all p>0.15. Irrespective of group: VL volume was larger (422±96 vs VM: 300±67 cm^3, p<0.01) and fascicle length was smaller (10.8±1.2 vs VM: 13.1±1.5 cm, p<0.01). Subsequently, VL PCSA was larger (39.2±7.7 vs VM: 23.0±4.8 cm^2, p<0.01). Activation was ~2% MVC higher in VL than VM across all tasks (all p<0.01). VM moment arm (39±4 mm) was larger than VL (36±4 mm, p<0.01). In both groups, and all tasks, VL contributed approximately 66% (range 39-83%) of the total VL+VM force. CONCLUSION: We provide no evidence that the distribution of VL and VM muscle force differs between adolescents with and without PFP.

S1-5: Effect of shoulder pain on neuromuscular control

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Background: Full-thickness rotator cuff tears (FTRCT) affect up to 32% of the population (mostly people older than 50 years) and are one of the most painful and debilitating shoulder diagnoses. One of the primary challenges for clinical decision-making is the poor association between the presence of FTRCT (detected by medical imaging) and pain, as studies have shown that 2/3 of people with FTRCT are asymptomatic. This challenges the notion that FTRCT causes pain, and highlights the fact that symptoms may be explained by other variables. Aside from tear size, it is unclear which factors lead to pain in patients with FTRCT. Some have argued that as long as normal shoulder control is preserved, individuals with FTRCT could remain pain free, as abnormal glenohumeral and scapulothoracic kinematics may be a precipitating factor for the development of pain. Shoulder control relies heavily on sensory information and on the processing and integration of this information by the central nervous system. Shoulder control can therefore be compromised by several factors, and the mechanisms involved in such changes are not well understood. Objectives: Two projects will be presented to better understand the impact of pain on the shoulder control. The objectives of these projects were to: 1. To evaluate the effect of experimental shoulder pain on arm movement control during reaching tasks; 2. To compare shoulder control between individuals with symptomatic FTRCT and healthy age-matched controls. Methods: For objective 1, healthy subjects were exposed, during a reaching task in a virtual reality environment, to pain (single bolus injection of hypertonic saline injection into the subacromial space). The reaching task was performed before and after the injection. Shoulder control was characterized by movement patterns using EMG activity and upper limb kinematics. For objective 2, 30 adults with a symptomatic FTRCT and 30 age-matched healthy controls took part in a single evaluation. Participants completed a questionnaire on sociodemographic data, followed by a physical examination of the shoulder, that included maximal voluntary contraction in humeral abduction and lateral rotation. Finally, ultrasonographic measurements of the acromiohumeral distance at 60° of humeral abduction was performed (to estimate the narrowing of the subacromial space). Results: Results show that shoulder control was affected by the presence of experimental pain in healthy subjects, but that accuracy during reaching was maintained. As for individuals with FTRCT, their acromiohumeral distance was smaller and their maximal strength was decreased compared to the healthy controls. Discussion: These results improve our insight into the adaptation of shoulder control when confronted to pain and our understanding of the development of sensorimotor control deficits following pain. They suggest that preserving shoulder control might be key to avoid pain following a FTRCT.

Symposium 2: Motor Unit Firing Characteristics and Their Relationship to Muscle Dynamics

S2-1: Rate of force development influences rate of fascicle shortening and motor unit recruitment properties

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BACKGROUND AND AIM: Studying the neural control of regulating changes in force development is highly relevant to our general understanding of movement. Findings from single motor unit recordings generally reveal an earlier recruitment and increased discharge rate of motor units when rate of force development is increased. However, the influence of fascicle shortening velocity, which is strongly influenced by muscle activation and tissue compliance, on discharge and recruitment properties has not be investigated. We hypothesised that an increase in the rate of force development would result in an increase in fascicle shortening velocity which in turn would result in a decrease in the muscle's maximal force capacity, thereby lowering motor unit recruitment thresholds but increasing discharge frequencies to attain the required force. METHODS: Data was collected on three separate occasions from two separate participant groups. Participants performed randomised isometric plantar flexion ramp contractions to a defined torque at three different rates: 2% MVC/s (slow), 10% MVC/s (medium) and 20% MVC/s (fast). B-mode ultrasound videos were recorded from the thickest part of the medial gastrocnemius (MG) muscle belly. MG fascicle length was measured from the video semi-automatically and velocity calculated. Bipolar surface EMG electrodes were placed on the muscle bellies of MG, soleus (SOL) and tibialis anterior (TA) to record and measure root mean square (RMS) amplitude. Motor unit discharges were recorded from MG using fine-wire electrodes with classification of single units based on shape and amplitude using a semi-automatic approach. The same units were identified across all three ramp rates. RESULTS: The absolute change in MG fascicle length was not different between the three contraction speeds (mean of 5.9 ± 2.8 mm). However, the mean shortening velocity of the MG fascicles significantly increased with increasing ramp rate from a minimum of 0.4 ± 0.2 mm/s to a maximum of 4.1 ± 1.9 mm/s. The increase in fascicle shortening velocity results in a theoretical drop in maximal torque capacity of up to 7%. The recruitment threshold of the discriminated motor units (n=30) was significantly lower in the fast and medium conditions compared to the slow condition. The initial and final discharge frequencies of all units were not different between the three ramp rates. The mean discharge frequency was also not different between the ramp rates (fast: 9.6 ± 2.3 Hz, medium: 9.5 ± 1.5 Hz slow: 9.7 ± 2.3). EMG RMS amplitudes of MG and SOL increased across the slow-to-fast speeds. EMG RMS of TA was not different between the three conditions. CONCLUSIONS: Taken together the results confirm our hypothesis that MG fascicle shortening rates increase when performing isometric plantar flexions with faster ramps. To achieve the required torque the motor units we recorded during the fast ramps were recruited earlier, although we found no increase in their discharge rates. However, the surface EMG amplitude recorded from MG and SOL significantly increased with ramp rate, which can be interpreted as a strategy to recruit additional motor units, rather than increase discharge rates, to achieve the required rate of torque increase.

S2-2: Motor unit decomposition from high-density surface EMG during dynamic contractions at different speeds in the tibialis anterior muscle

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BACKGROUND AND AIM: There are limitations on the use of surface EMG to describe neural control of movement during dynamic contractions, such as signal nonstationarity, movement artifacts, electrode shift and variations in the conductivity of the tissues. Recent studies have extracted individual motor unit properties from high-density surface EMG (HD-sEMG) during cyclic and slow movements (De Luca et al. 2015; Glaser & Holobar, 2018). However, the majority of studies on this topic explore isometric contractions, and our knowledge on motor unit changes during dynamic contractions and in particular at different movement speeds is limited. The aim of this study was to identify motor unit behavior in repeated dynamic contractions using HD-sEMG recordings and determine if the same motor units could be tracked across different speeds of movement. METHODS: Four young adults performed 20-degree ankle plantarflexion and dorsiflexion movements at 5, 10 and 20 degrees/s. The subjects were asked to maintain a constant 10 % MVC (isometric) load during the task. Isometric periods of 2s were included in the transitions from concentric-to-eccentric and eccentric-to-concentric contractions. HD-sEMG (128 channels), ankle joint torque, and joint angles were recorded simultaneously. EMG signals were decomposed using convoluted blind source separation (Negro et al. 2016) and the extracted innervation pulse trains were corrected to compensate for changes in MUAP shapes during movement. Motor units identified in the three different contraction speed were matched, and those units present in all movement speeds were reported. RESULTS: The number of motor units discharging continuously (>90% recording time) and intermittently were identified. There were 24±2, 23±2 and 20±3 motor units decomposed at 5, 10 and 20 degrees/s respectively. From these totals, there were 51 motor units (13±3 per participant) which were present in all three movement speeds, with an average 2D cross-correlation of 0.9±0.1%. The majority of the matched motor units (27/51, 7±2 per participant) were firing intermittently, whereas 18 motor units (4±3 per participant) were firing continuously. Interestingly, some motor units (6/51) changed the behavior (from intermittent to continuous or vice-versa) across the different speeds. Moreover, the average discharge rate was similar among the matched continuous (13.8±2, 13.8±2 and 14.0±2 pps at 5, 10 and 20 degrees/s, respectively) and intermittent motor units (13.5±2, 14.0±2 and 14.1±2 pps at 5, 10 and 20 degrees/s, respectively). CONCLUSIONS: These preliminary results suggest that it is possible to extract relevant neural features of the tibialis anterior muscle during concentric and eccentric actions at different movement speeds. Moreover, the identification of motor units consistently recruited across different speed represents an important advance on the use of HD-sEMG to investigate the neural drive to muscles in dynamic contractions.

S2-3: Adjustments to motor units during experimental muscle pain are force and velocity dependent

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Introduction: Most of the knowledge about motor unit control strategies during painful conditions comes from research performed during sustained contractions of low speed and force. These previous studies have recognized that discharge rate decreases when nociceptive substances are infused into the muscle. Despite this consistent observation, it is not currently known how the central nervous system controls motor unit behavior during painful muscle conditions at high force levels and fast contractions. In this project, consisting in two experiments, we aimed to compare the behavior of tibialis anterior motor unit firing properties during low (20% MC) and high-force (70% MVC) contractions and during low (sinusoidal target at 0.25Hz, 20% MVC) and high speeds (sinusoidal target at 1Hz, 20% MVC). Methods: Surface EMG signals were recorded from 15 participants (26 (3) years, 6 females) using a matrix of 64 electrodes while performing ankle-isometric dorsiflexion. In both experiments, signals from the four different conditions [baseline (no pain), isotonic (injection of control non-painful solution to the muscle), pain (injection of 0.5 ml of hypertonic saline solution) and post-pain] were decomposed and the same motor units were tracked across conditions. Results: For experiment 1, at 20% MVC, discharge rates decreased significantly in the painful condition (baseline vs. pain: 12.7 (1.1) Hz to 11.5 (0.9) Hz, p<0001). Conversely, at 70% MVC, discharge rates increased significantly during pain (baseline vs. pain: 19.7 (2.8) Hz to 21.3 (3.5) Hz, p=0.029) and recruitment thresholds decreased (baseline vs. pain: 59.0 (3.9) %MVC to 55.9 (3.2) %MVC, p=0.02). In experiment 2, discharge rates decreased significantly during the 0.25Hz contractions (baseline vs. Pain: 12.3 (1.4) Hz to 11.7 (1.3) Hz, p<0.05) but not during the 1Hz contractions (baseline vs. Pain: 11.8 (1.8) Hz to 11.8 (1.4) Hz, p=0.9). Conclusion: These results show that adjustments to motor units during pain are force and velocity dependent. As during fast and strong contractions, a larger recruitment of high-threshold motor units is required, it is possible that an increase in excitatory drive to this pool compensates for the inhibitory influence of nociceptive afferent inputs on low-threshold motor units. These differential mechanisms allow the force output to be maintained during acute pain but this strategy could lead to increased muscle fatigue and symptom aggravation in the long term.

S2-4: Motor unit firing rate patterns during different rates of ramp contractions and the influence of muscle spindle activity

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Our work suggests that the firing rates of higher-threshold motor units (MUs) at steady force are greater following a faster rate of increase (ramp) in isometric strength. However, the MU action potential (AP) amplitudes were relatively smaller at the higher recruitment thresholds during the faster ramp contractions. Therefore, suggesting that the greater firing rates during the faster ramp contraction might primarily be the result of delayed recruitment of larger MUs that achieve lower firing rates. In addition, there were no differences in firing rates between the contractions when expressed as a function of AP amplitudes that may suggest recruitment position was altered rather than changes in firing rates of a MU. Sensory information from the muscle might play a role in the different MU firing rate and recruitment patterns as a function of the rate in a ramp contraction. It is well known that muscle spindles influence MU activity. The application of prolonged continuous vibration diminishes muscle spindle activity. The MU firing rate pattern during a faster ramp are similar to a slower ramp contraction when vibration is applied continuously prior and during the contraction. Furthermore, vibration did not change the MU firing rate pattern during a slower ramp contraction. Muscle spindle activity may have a stronger influence on MU firing rate and recruitment patterns during a faster ramp in comparison to a slower ramp contraction.

Symposium 3: Eccentric vs Concentric Contractions: Basics and Applications

S3-1: Neural control of eccentric and concentric muscle contractions

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The role of the nervous system during muscle contractions is to activate the muscles so that they perform the desired task. During dynamic muscle contractions, the controlling drive has to take into account the load characteristics, as well as muscle properties including the length-tension and force-velocity relationships. It is well known that when an active muscle is lengthened, it produces more force than when it shortens. This means that a concentric (shortening) action such as bending the elbow to pick up an object requires more muscle activity than the reverse eccentric (lengthening) action to put the object down. This difference can be seen as lower amplitude of the surface electromyogram (EMG) during eccentric actions. Moreover, single motor unit recordings show that discharge rates are lower during eccentric actions and fewer motor units are recruited. At the spinal level, lower motor unit discharge implies a net decrease in excitation of the motoneurones. Consistent with this, H reflexes and responses to descending tract stimulation are reduced. However, muscle spindle afferents fire more during lengthening than shortening contractions as they are sensitive to muscle stretch. Potentially, this could increase reflex excitation at a time when less excitation is required. In some tasks, presynaptic inhibition of the muscle spindle afferents may moderate the sensory input before it reaches the motoneurones. Alternatively, increased reflex input may be balanced by a reduction of voluntary descending drive. At a cortical level, imaging studies show different patterns of cortical activation in eccentric compared to concentric contractions, and movement related cortical potentials in the electroencephalogram are larger with eccentric movements. Additional sensory feedback may contribute to this increase. It has also been suggested that eccentric actions have a higher level of difficulty with a requirement for increased motor planning. Complex eccentric tasks have a high cognitive load, and simple lengthening contractions show more variability than matched shortening contractions. Motor cortex stimulation shows smaller excitatory muscle responses (motor evoked potentials) during eccentric actions but this may reflect decreased spinal rather than cortical excitability. Reports on inhibitory responses (silent periods) are inconsistent, while paired-pulse testing suggests that intracortical inhibition is lower in concentric than eccentric actions. However, these responses may be specific to muscles or tasks. Overall, concentric and eccentric actions differ in sensory feedback, have differences at spinal and cortical levels in the motor pathway, and require different output from the nervous system for successful task performance. Eccentric actions are more efficient, but may be more difficult to control. Yet, it remains unclear if there are key mechanisms that comprise a specific strategy for control of lengthening contractions.

S3-2: In vivo musculotendinous behavior during dynamic joint actions hints at the different view of eccentric and concentric contractions at the muscle fiber level

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Skeletal muscles typically take the form of muscle-tendon unit (MTU) where muscle fibers and tendinous tissues act as activation-driven actuators and viscoelastic springs respectively. Even during an isometric joint action, muscle fibers shorten while the tendinous tissues are elongated as one develops force, and vice versa as the exerted force decreases at the same joint position. Thus an isometric joint action is not purely isometric, but involves concentric and eccentric contractions at the muscle fiber level. Muscle-tendon interactions are particularly evident in MTUs with highly pennated fibers and long tendinous tissues, such as the triceps surae and vastus lateralis. Because of this muscle-tendon interaction, during concentric and eccentric isokinetic joint actions where the angular velocity is kept constant by a dynamometer, shortening velocities of muscle fibers are different from those of MTU (the difference depends on the initial condition of the movement). We showed that the different magnitude of tendinous tissues lengthening among velocities (due to differences in muscle force) during maximal voluntary isokinetic concentric knee extensions was the reason for the shape of humans' torque-velocity relationship that often lacks the hyperbolic nature. Another piece of evidence exists in the notion that in vivo muscle fiber behavior also accounts for the joint-angle dependence of maximal eccentric joint torque development. Interestingly, however, during a stretch-shortening type of exercise where the gastrocnemius MTU is lengthened then shorten, muscle fibers follow the sequence of passive (not active) lengthening then isometric contraction, before shortening. Thus the muscle fibers experience isometric-concentric contractions, unlike the eccentric-concentric actions for MTU and the joint. The first isometric part for the muscle fibers is unique in a way that it is achieved by changing activation levels, i.e., it is skillful. The whole movement is characterized by the greater positive joint power, due to the added velocity by tendon shortening through a "catapult action" (rapid shortening from the state of being stretched then kept in length like a catapult). Following studies have shown that MTU performance during the stretch-shortening type of exercise depends on the velocity and intensity of movement, and on the activation strategy of the individuals. The neural control over the muscle-tendon interaction, is the key to the execution of the intended motor performance. Failure to do this pertinently, such seen in unaccustomed movements and/or skillful movements performed in a fatigued state, can hinder optimal muscle-tendon interaction that ends up with poor motor performance, and incidentally, musculotendinous damage in varied grades. Collectively, there is need for understanding what muscle fibers are doing and/or should do, when one interprets the outcome of the human joint performance carried out dynamically, and even statically.

S3-3: Muscle responses and adaptations to eccentric versus concentric muscle contractions

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In our movements, three types of muscle contractions (actions) are performed; isometric (static): Force = Load, concentric (shortening): Force > Load, and eccentric (lengthening): Force < Load, from the relationship between the force produced by muscles and the load to the muscles. In some movements, either concentric or eccentric contractions are predominant. For example, the knee extensors perform more concentric contractions when going up stairs, but more eccentric contractions when walking down stairs. Unaccustomed exercises consisting of eccentric contractions result in muscle damage that is characterized by prolonged decreases (e.g. > 3 days) in muscle functions such as maximal voluntary contraction (MVC) strength, delayed onset muscle soreness (DOMS), increases in muscle proteins such as creatine kinase in the blood, increases in B-mode ultrasound echo-intensity or magnetic resonance T2 relaxation time, impairment of proprioception, and histological changes in myofilaments and extracellular matrix. In contrast, concentric exercises do not normally induce these changes. When the same or similar eccentric exercise is repeated within several weeks, the changes described above are attenuated or eliminated, which is known as the repeated bout effect. The magnitude of muscle damage induced by maximal eccentric contractions is also reduced by low-intensity eccentric contractions, isometric contractions at a long muscle length, and maximal or submaximal eccentric contractions performed by the contralateral homologous muscles. However, concentric contractions do not confer the protective effect against eccentric contraction-induced muscle damage. Resistance exercise training produces multiple adaptations to not only the muscles that are stimulated in the training but also to other organs including brain, internal organs and bones. Several studies reported greater increases in muscle functions and size by eccentric than concentric exercise training. For example, Chen et al. (Front Physiol 2017) reported that eccentric training of the knee extensors improved muscle strength, physical function, insulin sensitivity and blood lipid profile of older adults better than concentric training that was performed once a week for 12 weeks with progressive increases in the load from 50 to 100% of maximal concentric strength for concentric training and from 10 to 100% for eccentric training. Chen et al. (Med Sci Sports Exerc 2017) also showed that descending stair walking (eccentric) was more effective in improving muscle strength, functional fitness, insulin sensitivity and blood lipid profile when compared with ascending stair walking (concentric) performed by obese older women. It is not well understood how the stimulus for the adaptation process differs between eccentric and concentric contractions, and what physiological differences between the muscle contraction types lead to different adaptation processes. These will be explored in the presentation.

Symposium 4: Neuromuscular control of body mechanics: novel insights from innovative experimental methods

S4-1: Posture-dependent changes to the active regulation of shoulder stiffness

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The shoulder is the most complex and mobile joint in the human body, but mobility comes at a cost. The shoulder is also the joint most likely to dislocate. Regulating the mechanical integrity of the shoulder is critical for activities of daily living. Shoulder instability, defined clinically as pain and disability associated with an inability to keep the humeral head centered in the glenoid fossa, is common but treatments are often not effective. Rehabilitation aimed at strengthening the muscles regulating stability and surgeries targeting passive structures can have inconsistent outcomes. One reason is that we have a poor understanding of the mechanisms contributing to shoulder stability, particularly the translational stiffness needed to restore the head of the humerus towards the center of the glenoid fossa when displaced. Many have assessed shoulder stiffness during passive conditions, but the active conditions in which muscles can substantially alter joint mechanics have rarely been studied. The purpose of this work was to quantify the passive and active contributions to the translational stiffness of the shoulder in a neutral posture and in apprehension, where individuals with shoulder instability experience symptoms. Data were collected from seventeen healthy adults. Mechanical properties of the shoulder were measured using a linear actuator to apply small, stochastic, anterior-posterior perturbations that translated the humerus in the glenoid. Measurements were made in a neutral posture (arm at side, abducted by 90°; elbow in horizontal plane, flexed to 90°) and in apprehension (change to 90° external rotation) as subjects generated isometric torques in six orthogonal directions. Nonparametric system identification was used to estimate shoulder impedance from the measured displacements and forces. Results are summarized by stiffness, the static component of shoulder impedance. EMGs were measured from 11 shoulder muscles using surface and intramuscular recordings. These were used to determine which muscle groups contributed most to the measured stiffness changes; linear mixed effects models between EMGs and stiffness were used for this purpose. Muscle activation significantly increased the translational stiffness of the shoulder in all experimental conditions. Passive stiffness was greatest in apprehension (Fig. 1A), but the active modulation of stiffness was lowest in this same posture (Fig. 1B). Surprisingly, activation of the rotator cuff muscles had no significant relationship to the modulation of stiffness ($p=0.15$), which was dominated instead by the more superficial muscles acting about the shoulder ($p<0.001$). These results demonstrate the importance of muscle activation in regulating the translational stiffness of the human shoulder and provide insight to which muscles might be best to target during rehabilitation aimed at reducing shoulder instability, including in the postures most vulnerable to injury.

S4-2: Coordination of quadriceps muscles in the rat suggests minimization of joint stresses rather than simplification of task performance

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Co-variation between muscle activations during behavior has been suggested to reflect simplification of task performance, so that muscles with similar contributions to task performance are controlled as a unit. For instance, the quadriceps muscles vastus medialis (VM), vastus lateralis (VL), and vastus intermedius (VI) all produce similar knee extension torques and so might be activated together to reduce the number of variables that need to be specified to produce behavior. Alternatively, muscle co-variation might reflect regulation of low-level aspects of movement, such as stresses within joints. In this context, activation of VM and VL might be tightly coordinated to minimize the net mediolateral forces on the patella. We examined these issues by recording EMGs from quadriceps muscles during locomotion in rats across a range of inclines and speeds. We found that co-variation between VM and VL was stronger than that between any other quadriceps muscles across task conditions, consistent with the hypothesis that muscle co-variation reflects regulation of mediolateral patellar forces, rather than simplification of task performance. We then examined the mechanisms underlying this strong co-variation between VM and VL, evaluating whether this coordination was due to sensory feedback from afferents within the joint. We injected lidocaine into the knee joint to silence joint afferents and evaluated changes in limb kinematics, muscle activations, and co-variation patterns. Co-variation between VM and VL was not significantly altered following lidocaine injection, although the co-variation between these muscles and VI was reduced. There were no significant changes in limb kinematics or mean muscle activations following lidocaine injections. These results suggest that the coordination between VM and VL responsible for minimization of mediolateral patellar stresses is specified using other sensory modalities or through central mechanisms.

S4-3: Effects of postural demand on responses to cortical stimulation

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There is currently no non-invasive method by which deep brain structures such as the reticulospinal tract (RST) and vestibulospinal tract (VST) can be reliably probed in human subjects. Recent evidence, however, suggests that the muscle response elicited by transcranial magnetic stimulation (TMS), a noninvasive tool used to activate neurons in the cerebral cortex, is partially mediated by at least one of these deep brain structures. We report on two experiments designed to determine whether modulating the engagement of subcortical postural control networks preferentially modulates long-latency components of the response to TMS in the lower and upper limbs. In Experiment 1, TMS was used to induce motor evoked potentials in the gastrocnemius muscle of nine healthy participants while the responsibility of the same muscle for maintaining upright balance was modified by changing the leg(s) in contact with the floor. Experiment 2 replicated this technique for the triceps brachii by creating a task in which elbow extension was required for balance and altering the responsibility of a single arm for maintaining equilibrium. The level of tonic activity in the target muscles was matched across conditions in each experiment. In the lower limb, a significant increase was observed in the long-latency component of the response to TMS when the target gastrocnemius provided full postural support compared to the conditions in which the same muscle provided no postural support ($p = 0.013$). This effect was duplicated in the left and right gastrocnemius. Similar observations were made in the upper limb, with long-latency components of TMS responses in the left triceps brachii being preferentially facilitated when extension of the left arm was fully responsible for maintaining balance. These results support previous suggestions that TMS responses in both upper and lower limb muscles are produced by at least two distinct neural pathways, with late portions of the response likely being attributable to subcortical pathways with balance responsibilities.

S4-4: The role of estrogen on reciprocal inhibition of the Soleus

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BACKGROUND AND AIM: Our prior work indicates that estradiol has an undisguisable effect on motor neuron excitability. In this study, we seek to explore the effect of estrogen at the network level with a primary focus on a neuronal network that is defined on the net as inhibitory. METHODS: We conducted a peripheral nerve stimulation paradigm to quantify changes in the state of the reciprocal inhibition in a model with naturally fluctuating hormones: young women who are non-users of oral contraceptives. We measured reciprocal inhibition 15 separate times on days spread throughout the menstrual cycle, while also documenting each participant's current level of estrodiol. Participants laid prone while performing isometric ankle plantarflexion to generate a torque of 10% of their maximum generated torque, found using a maximum voluntary contraction protocol. While plantarflexing, we stimulated the common peroneal nerve at least 10 times and recorded the reciprocal electromyographic (EMG) response of the soleus muscle at 2000 Hz using a pair of gel electrodes (diameter = 1 cm, distance = 2.5 cm) placed according to SENIAM recommendations. EMG signals were rectified and low-pass filtered using a 4th order Butterworth filter at 500 Hz. Reciprocal inhibition was measured as the difference between the mean pre-stimulus EMG (from a window 40-5 ms before stimulation onset) and the minimum EMG (from a window 30-60 ms after stimulation onset), and expressed as a percentage of the maximum voluntary EMG. A one-way ANOVA with posthoc pairwise comparison tested for significant differences in the reduction of EMG amplitude. RESULTS: This ongoing study has currently enrolled 7 women, and we present results from one subject thus far. We observed a consistent depression in EMG activity around 50 ms after the stimulus in every testing session. However, we found that the amplitude of this depression changed over the 15 testing sessions, presenting significantly less inhibition in the days leading to peak estrodiol ($p < 0.001$). CONCLUSIONS: Our preliminary data indicate that the amplitude of the reciprocal EMG response of the Soleus modulates with the levels of circulating estradiol concentration. Understanding the changes in spinal neural state associated with estrogen may provide

insights on our understanding of the effect of endogenous hormones on neuromuscular control with significant clinical implications.

Symposium 5: International Motoneuron Society: from motoneuron activity to motor control

S5-1: Reverse engineering motor unit firing patterns to identify motoneuron input patterns

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BACKGROUND AND AIM: Recent advances in array electrodes placed on the surfaces of muscles and in decomposition methods applied to the resulting signals now allow simultaneous recording of many motoneuron firing patterns during normal in humans. These methods have the potential to revolutionize our understanding of the organization of motor commands in humans. Moreover, both the electrode structures and the decomposition methods are ongoing continual improvements, as discussed in this symposium. To understand these remarkable data sets, we have adapted our realistic models of motoneurons to run effectively on highly parallel supercomputers. We are using these models to implement a reverse engineering approach to achieve a new level of understanding of the structure of excitatory, inhibitory and neuromodulatory synaptic inputs that generate motor commands. METHODS: A pool of motoneuron models, based on many years of study in animal models, was created that realistically captures motoneuron input-output behavior in response to the synaptic excitation and inhibition generated by motor commands. These models also accurately capture the profound changes in this input-output behavior due to neuromodulatory inputs from the brainstem that release serotonin and norepinephrine. Using the supercomputers at Argonne National Labs, we examined the outputs of a pool of these simulated motoneurons in response to 1000's of combinations of excitation, inhibition and neuromodulation. The reverse engineering approach consists of analyzing the result set of simulated outputs to determine which best recreate a given pattern of firing of human motoneurons recorded via arrays. RESULTS: Computational time is greatly reduced by this approach. A set of 2000+ inputs would require more than 30 days of computation on standard computers; our implementation via supercomputers required 4 hours. Our analyses of these data thus far strongly support our ongoing hypothesis that, during slow or steady motor output, persistent inward currents (PICs) in the dendrites of motoneurons induce an enormous nonlinearity in the input-output function of the motoneuron. These PICs are the primary source of the acceleration, saturation and hysteresis that invariably characterize human motoneuron firing patterns in these behaviors. Fortunately, this same nonlinearity is proving to be a sensitive indicator of the relative amplitudes and patterns of excitation and inhibition. CONCLUSION: This new "reverse engineering" approach to analysis of motoneuron firing patterns has the potential to identify both the amplitudes and the patterns of the excitatory, inhibitory and neuromodulatory components of motor commands in humans. We are planning to make these methods widely available for us for labs studying both normal and pathological behavior at the motor unit level.

S5-2: Variations in motor unit discharge properties can predict time to task failure during submaximal contractions

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BACKGROUND AND AIM. During sustained submaximal contractions, muscle fatigue develops as a progressive phenomenon from the beginning of the contraction that leads eventually to neuromuscular failure. The interaction between central and peripheral mechanisms is likely responsible for it, but, due to limitations in the recording and tracking of individual motor units (MUs), clear evidence of this phenomenon has never been reported until now. In this study, we aimed to estimate the changes in MU discharge and muscle fiber contractile properties in two synergistic muscles using an advanced methodology to track individual MUs during the entire duration of a submaximal isometric contraction until task failure. METHODS. Sixteen participants performed a 30% MVC sustained isometric knee extension until exhaustion. For comparison, a non-fatiguing contraction at 50% MVC was recorded before the beginning of the fatiguing trial. Two grids of 64 surface electromyography electrodes were placed over vastus medialis and lateralis. Signals were divided into overlapping segments and each segment was decomposed (Negro et al. 2016) independently. MUs were tracked by cross-correlation of discharge times from the beginning to the end of the fatiguing contraction. Additionally, MUs were matched (Martinez-Valdes et al. 2017) between the end of the fatiguing task and the non-fatiguing 50% MVC contraction. MU twitches were estimated using a recently developed technique (Negro & Orizio, 2017). A computational model (Dideriksen et al 2012) was used to interpret the observed changes in MU properties. RESULTS.: During the sustained fatiguing contraction, MUs of both synergistic muscles decreased their discharge rate until ~40% of the endurance time (reversal time) and then increased their discharge rate until task failure. This reversal in firing behavior predicted total endurance time and was matched by opposite changes in twitch force (increase followed by a decrease). The computational model could correctly reproduce the experimental results. Peak discharge rates at task failure showed saturated behavior in comparison to the discharge rates of the same units identified during a non-fatiguing 50% MVC contraction. CONCLUSIONS. These results show that the MU discharge properties can be described by two phases and are paralleled by changes in MU twitch properties during the course of an endurance contraction. Eventually, the contraction cannot be sustained possibly due to progressive motoneuron inhibition and/or decreased excitability, since the peak discharge rate at the end of the endurance task saturates at a slower frequency compared to a higher-force non-fatiguing contraction.

S5-3: Short-term plasticity of the human motor command

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BACKGROUND AND AIM: The discharge spinal motoneuron is critical for muscle force production and ultimately movement. This discharge is regulated both by synaptic drive to and intrinsic excitability of the motoneuron. Our goal here is to quantify population estimates of human spinal motoneuron excitability within and across days. METHODS: Twelve individuals took part in 3 identical experimental sessions on non-consecutive days. On each day, the subject's right foot was affixed to an isokinetic dynamometer with a load cell aligned to the ankle axis of rotation and a high-density surface EMG array electrode was placed on the tibialias anterior. Subjects performed three sets of three time varying contractions to 20% maximum and separated by 10 s of rest. Offline, discharge times of active single motor units were decomposed from the EMG signal using a semi-automated blind source separation decomposition algorithm (Negro et al. 2016). The excitability of spinal motoneurons was assessed by quantifying the difference in onset and offset of a higher threshold unit with respect to a lower threshold unit (delta-f). RESULTS: Within each of these 324 contractions, an average of 21±8 motor units were decomposed resulting in 186.0±142.6 delta-f comparisons per contraction. No change in maximal discharge rate was observed across contractions ($p>0.05$). A significant decrease in delta-f was observed across contractions separated by 10s rest ($p<0.05$). This was mediate by an unequal decrease in both recruitment and derecruitment threshold across contractions. Such findings are confirmed when tracking the same motor unit pairs across contractions. Lastly, a negative relationship is observed when the initial delta-f is plotted against the mean change in delta-f on subsequent contractions. Such results are consistent across days. CONCLUSIONS: The motor command is not static across contractions separated by 10s. This history of submaximal contractions is sufficient to induce alterations in motor unit recruitment and rate coding. Further, these data demonstrate the excitability of spinal motoneurons may not be modulated equally across the pool. Instead, those motoneurons with relatively high levels of excitability on the initial contraction will decrease their excitability on subsequent contractions, whereas those motoneurons with relatively low levels of excitability will increase their excitability, producing a rotation in intrinsic excitability across the motoneuron pool.

S5-4: Robust estimation of reflex activity from populations of motor units

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BACKGROUND AND AIM. Both simulation and experimental studies have shown that the amplitude of the reflex response is dependent on its background discharge frequency and membrane noise of the spinal motoneuron (MN). However, it is unclear how these two factors effect reflex response strategy among a population of motor units recorded in the same contraction. Recent advances in motor unit decomposition from high-density surface EMG signals provide the possibility to extract tens of motor units in the same contraction. Using population analysis, multidimensional relation between reflex amplitude, discharge rate (as a measure of net input current), and coefficient of variation (as a measure of membrane noise) can provide more reliable estimation of excitability in the same contraction. METHODS. High density surface EMG signals were collected from tibialis anterior muscle under two reflex conditions (n=6 and 6) and decomposed into their corresponding motor unit discharge times (Negro et al. 2016). The mono-synaptic H-reflex and the di-synaptic reciprocal inhibition of a large population of motor units (131 motor units for the H-reflex, and 169 for the reciprocal inhibition) were recorded at 10% and 20% of maximum voluntary contraction. The reflex amplitudes were measured using the cumulative sum of peri-stimulus frequencygram and the regression between the reflex amplitude and the pre-stimulus mean discharge rate and the coefficient of variation of inter-spike interval were estimated. Simulations were performed using a model of 460 MNs for a specific case as the membrane resistance of MNs changed gradually while the afferent synaptic input was maintained constant for the entire pool. RESULTS. A significant positive regression was found between the discharge rate and the reflex amplitude for 10 subjects at 10% MVC (4 excitation, 6 inhibition; $p < 0.05$) and for 8 subjects at 20% MVC (3 excitation, 5 inhibition; $p < 0.05$). Additionally, we found that the slope coefficients of the linear regressions were positively correlated with the coefficient of variation of inter-spike-intervals ($p<0.05$). The simulation results agreed with the experimental results. CONCLUSIONS. The results suggest that the motor units with different thresholds have different responses to excitatory or inhibitory postsynaptic potentials. This response is influenced by both the amplitude and noise characteristics of the background level of synaptic drive.

S5-5: Stroke-related changes in motor unit firing behavior

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Ischemic conditioning (IC) on the arm or leg has emerged as an intervention to improve strength and performance in healthy populations, but the effects on neurological populations are unknown. The purpose of this study was to quantify the effects of a single session of IC on knee extensor strength and muscle activation in chronic stroke survivors using high density surface EMG arrays. Maximal knee extensor torque measurements and surface EMG were quantified in 10 chronic stroke survivors with hemiparesis before and after a single session of IC or sham on the paretic leg. IC consisted of 5 min of compression with a proximal thigh cuff (inflation pressure = 225 mmHg for IC or 25 mmHg for sham) followed by 5 min of rest. This was repeated five times. Maximal knee extensor strength, EMG magnitude, and motor unit firing behavior were measured before and immediately after IC or sham. IC increased paretic leg strength by 10.6 ± 8.5 Nm, whereas no difference was observed in the sham group (change in sham = 1.3 ± 2.9 Nm, $P = 0.001$ IC vs. sham). IC-induced increases in strength were accompanied by a 31 ± 15% increase in the magnitude of muscle EMG during maximal contractions and a 5% decrease in motor unit recruitment thresholds during sub-maximal contractions. This study provides evidence that a single session of IC can increase strength through improved muscle activation in chronic stroke survivors.

S5-6: Characteristics of the motor unit action potential shape in proximal and distal arm muscles in individuals post-stroke

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BACKGROUND AND AIM. The ability to examine characteristics of motor unit populations in individuals with neurological injury is crucial for understanding central and peripheral mechanisms of motor impairments. Spectral analysis of surface EMG has often been used to estimate central and peripheral characteristics of a motor unit population, such as average conduction velocity, proportion of muscle fiber types, and pattern of motor unit recruitment. This estimation is based on the assumption that the sEMG adequately reflects the frequency characteristics of the underlying motor unit action potentials (MUAP). However, sEMG has limitations in this respect, based on physiological and non-physiological factors that influence its frequency content. METHODS AND RESULTS. We recently presented a method (McPherson et al., 2016) to examine characteristics of a motor unit population more accurately assessing the distributions of frequency content and amplitude for a collection of individual MUAPs, which were identified using high-density sEMG decomposition (Negro et al., 2016). We applied this approach to motor unit discharge extracted from proximal and distal muscles (deltoid, biceps, finger flexors) from post-stroke individuals and age-matched controls, demonstrating differences in MUAP median frequency and RMS amplitude across muscles and between groups that were not present when calculated using sEMG. DISCUSSION. In the present study, we extend these preliminary findings by exploring the spatial distribution of MUAP frequency and amplitude across the surface of the muscles to more completely evaluate differences between post-stroke and control groups and among proximal and distal muscles.

S5-7: Evaluation of neural control of pectoralis major in different arm tasks at low effort levels: A combined high-density electromyography and neural decoding approach

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BACKGROUND AND AIM. Pectoralis major is a multi-functional muscle involved in humeral mobility and stability. Although it assists in the performance of numerous functional tasks, its neuromusculoskeletal control is not well understood. However, implications in understanding the neuromusculoskeletal control of this muscle are vast, from fundamental shoulder mechanics, to clinical applications, where pectoralis major function is compromised, and lastly in exercise settings, where understanding how to train pectoralis major is relevant in optimizing performance and preventing injury. METHODS. Data from eleven and eight healthy, right-hand dominant young males was collected as a part of two different protocols. Participants performed following submaximal, ramped isometric tasks: vertical adduction from 90° abduction and 60° abduction, internal rotation from 60° abduction, horizontal adduction, or flexion at two efforts: 15% and 25% scaled to task-specific maxima (MVE). Pectoralis major activation was recorded using two high-density electromyography arrays (HD-sEMG; 128 channels; EMGUSB2+, OTBioelecttronica) in monopolar mode at 2048 Hz. HD-sEMG signals were decomposed using convolutive blind source separation (Negro et al. 2016). Mean discharge rate was quantified on 10-second segment within the hold for each motor unit identified. The individual two-dimensional motor unit action potential profiles were extracted using spike trigger averaging. RESULTS. Total number of motor units decomposed across tasks at 15% MVE was 189 and at 25% MVE was 139. Differential spatial distribution of motor unit action potentials occurred across tasks. Specifically, in internal rotation, vertical adduction, and flexion multiple motor units were recruited in clavicular and sternocostal regions. In cases such as horizontal adduction, motor unit action potentials were distributed throughout all regions of the muscle. Mean discharge rate did not differ between 15% and 25% MVE for adduction at 60° ($p = 0.79$), flexion ($p = 0.22$), or horizontal adduction ($p = 0.19$). DISCUSSION. For the first time, motor unit physiology in pectoralis major is explored in multiple arm tasks at different effort levels. Current findings indicate that increasing effort from 15% to 25% MVE in pectoralis shows a weak modulation of motor unit discharge rates across force levels. Further, spatial distribution of motor unit action potentials suggests differential topographical spread of motor unit activity within pectoralis major regions in different tasks. These insights have important implications in understanding the neural control of pectoralis major in healthy individuals.

Symposium 6: Tools to examine neuromuscular adaptation to muscle fatigue during movement execution

S6-1: Using wearable sensors to study changes in motor strategy and fatigue development in the lower limbs during gait in demanding real-life situations.

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BACKGROUND & AIM: In healthy individuals as well as in patients undergoing physical rehabilitation, the control of gait must be adjustable to the demands of the environment. During everyday activities or rehabilitation training, the gradual (and often unaware) development of muscle fatigue can lead to musculoskeletal (MSK) injuries or chronic pain. Indeed, to deal with force output reduction, the nervous system makes subtle modifications in motor unit recruitment and movement strategy. Initially efficient, these neural adaptations to muscle fatigue can put the MSK apparatus at risk of injury either through repetitive use of this adapted motor pattern, or through inappropriate reactions to unexpected external perturbations. As an additional challenge, part of the neural circuits at the basis of gait control are only 'open' during walking; fatigue therefore needs to be studied during gait, and ideally in an ecologically valid environment. Of interest to this field of research, recent advances in wearable technologies now give the possibility of assessing gait kinematics and EMG activity out-of-the-laboratory with much higher resolution that before. This presentation addresses the following question: Can simple metrics be extracted from modern wearable sensors to study changes in motor strategy and fatigue development in the lower limbs during gait in demanding real-life situations? METHODS: Data from several experiments involving healthy civilians and military personnel as well as neurological patients (multiple sclerosis, cerebral palsy and spinal cord injury) will be presented in the form of case series. Muscle activation patterns, EMG power spectrums, and kinematic template matching obtained in situations of graded complexity (from standardized 6-minute walk tests to controlled urban environment courses) will be quantified and discussed. RESULTS: Instrumented 6-minute walk tests are very sensitive and can show a degradation of movement kinematics and drops in EMG median frequencies in both healthy and patient populations. As the situation becomes more complex (e.g. urban environment courses), neural adaptations (changes in overall motor pattern) become more dominant. Shifts in EMG median frequency are still present, but their magnitude relative to background variability is reduced. Adding kinematic information regarding angular joint displacements helps identify the presence of fatigue. CONCLUSIONS: Wearable technologies can provide information about muscle fatigue development during gait. However, as the task complexity increases, the nervous system tends to use its full repertoire of adaptation strategies to slow down/minimize fatigue. As a result, it is therefore suggested to combine several metrics to detect muscle fatigue in complex walking situations.

S6-2: Advances in electromyography to identify motor control adaptations to muscle fatigue

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BACKGROUND AND AIM: Maintenance of the upright standing posture is achieved by activation of populations of motor units in the ankle plantarflexor muscles (soleus (SOL), medial (MG) and lateral gastrocnemius (LG)). High Density Surface Electromyography (HDS-EMG) allows the simultaneous recording of muscle activity in all three ankle plantarflexors across a wide surface area of the muscle, as opposed to conventional bipolar surface electrodes or intramuscular fine-wire electrodes which sample from motor units confined to a relatively small muscle region. HDS-EMG provides an innovative way of studying populations of motor units occupying different regions of the calf muscles to determine whether different muscle regions are recruited according to the task requirements (e.g., directionally-specific standing perturbations). Traditional EMG would be unable to detect this level of motor control. In fact, recent research from our laboratory using HDS-EMG showed that the central nervous system activates motor units within different regions of MG, LG and SOL in response to standing perturbations in different directions. The purpose of my talk is discuss the role of the central nervous system in the neural control of upright stance and to illustrate how HDS-EMG can identify the central nervous system adaptations that may occur following fatigue. METHODS: Participants balanced in single-leg stance and experienced a series of external perturbations of 1% body mass in three different directions; anterior, 60 degrees to right, and 60 degrees to left. High-density surface electromyography (HDS-EMG) was used to determine the amplitude and barycenter of the muscle activation. This task was performed before and after a fatiguing protocol. Fatigue was induced in the MG muscle by motor point electrical stimulation; 20Hz trains (10 pulses each) delivered every second for 6 minutes, repeated until low-frequency fatigue was induced. RESULTS: The fatiguing stimulation resulted in a selective fatigue in the MG muscle. In response to the external perturbations in standing, HDS-EMG was able to detect adaptations in the activation of the other plantarflexor muscles following the fatiguing protocol. CONCLUSIONS: The central nervous system activates the ankle plantarflexor muscles in a task-dependent manner during unipedal standing balance. HDS-EMG is a useful tool to identify the motor control adaptations to muscle fatigue.

S6-3: Effect of fatigue on upper limb neuromuscular control

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Background: Work-related shoulder disorders comprise a wide range of disorders affecting the muscles, tendons and bursae, potentially caused or aggravated by work. Physical workplace factors are known to play an important role in the development of work-related shoulder disorders. For examples, performing repetitive movements and maintaining fixed positions for long durations are physical factors contributing to work-related shoulder disorders. These factors overload the tendons and muscles, leading to a high risk of tears or micro tears in these structures, and ultimately to pain. Maladaptive patterns may also emerge following fatigue and if movements are repeated in a fatigued state, consolidation of maladapted patterns may occur. This can increase the physical stress on tendons and muscles, and lead to shoulder disorders. It is not yet known, however, when maladaptive patterns begin to emerge as a result of muscle fatigue. Objectives: The purpose of the talk will be to discuss the development of upper limb movement alterations following muscle fatigue and its impact on inter-joint coordination. Methods: 15 healthy right-handed individuals performed a dynamic fatigue task. Electromyographic (EMG, anterior deltoid, middle deltoid and upper trapezius muscles) and inertial sensors (modelling of elbow, shoulder and sternoclavicular kinematics) were first installed on the right upper limb. Then, each participant performed the task for five minutes. The dynamic task required to move from one box to another ten nuts placed in boxes of different heights (60, 90 and 100° of arm elevation) using only the right hand for 5 minutes. Fatigue was evidence by a decrease in the median frequency of the EMG power spectrum. Results: The mean maximal level of perceived exertion reached 5.2 +/- 1.8 on the Borg scale during the realization of the task. The median frequency of the EMG power spectrum significantly decreased ($p<0.001$) for the three muscles evaluated. For the middle and anterior deltoid, at all times the median power frequency was significantly different from the previous minute, except between the 4th and the 5th minute. From the third minute, alterations in upper limb kinematics started to emerge, with a significant decrease in humeral elevation and increase in sternoclavicular elevation. These alterations appeared when the drop in the median frequency reached 8 to 10% for the anterior and middle deltoid. Discussion: Muscle fatigue leads to significant movement alterations once a certain level of fatigue is reached. Workers should thus avoid reaching a level of muscle fatigue that leads to these movement impairments in order to avoid the development of maladaptive movement patterns.

S6-4: Muscle-specific changes in median frequency associated with fatigue: comparison of responses during gait and during MVC

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BACKGROUND. Muscle fatigue has been identified as an important risk factor for the development of some musculoskeletal disorders. The ability to detect neuromuscular adaptations associated with muscle fatigue development during dynamic tasks such as gait is therefore warranted. Recording and analyzing surface electromyographic activity (sEMG) may provide a simple, non-invasive approach to achieve this goal in real-life situations. The drop in median frequency (MF) of the sEMG has already been validated to assess neuromuscular fatigue during dynamic tasks. However, due to their fiber-type composition, different muscle groups might have different dynamics of adaptation, or ability to change their MF in response to muscle fatigue when performing a maximal versus submaximal intensity exercise. We hypothesized that the changes in MF of the working muscle, reflecting the neural adaptation to fatiguing contractions, would be intensity and muscle specific. METHODS. Thirty healthy participants performed 3 maximal voluntary contractions (MVC) and a walking bout before and after completing a muscle fatigue protocol. On separate days, muscle-specific protocols were performed for each of the following three muscle groups: knee flexors, ankle plantarflexors, and knee extensors. Neuromuscular adaptation to muscle fatigue was considered present when MF dropped together with a reduction in peak force during MVC. Changes in MF during MVC and gait at comfortable speed were compared. RESULTS. The muscle fatigue protocol resulted in a reduction in force output associated with a decrease in median frequency of the sEMG power spectrum. Larger drops in force were associated with larger drops in MF, with a similar pattern for MVC and gait. However, the slope of this relation was muscle-specific. CONCLUSION. Neuromuscular adaptation to muscle fatigue in knee flexors and extensors, as well as ankle plantarflexors can be measured using MF drops. These changes are muscle-specific but are minimally affected by the intensity of muscle contraction. ACKNOWLEDGEMENTS. This research was supported by the Sentinel North program of Université Laval, made possible, in part, thanks to funding from the Canada First Research Excellence Fund. This work was also supported by the Natural Sciences and Engineering Research Council of Canada.

Symposium 7: Beyond the Development of Novel Technologies for Physical Rehabilitation Based on Neuroscience

S7-1: Effects of novel approach using augmented reality that inspires self-body cognition in patients with stroke on motor function and resting-state brain functional connectivity

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Background and aim: Upper extremity motor function after stroke recovers in only 50% of all survivors at 6 months post-stroke. Therefore, maximizing recovery of motor function in the upper extremity after stroke is socially meaningful, but is a challenge for the area of rehabilitation science. This study aimed to clarify the effect of the kinesthetic perceptional illusion induced by visual stimulation (KINVIS) on upper limb motor function and the relationship between motor function and resting-state brain networks. Methods: Eleven patients with severe paralysis of upper limb motor function in the chronic phase (seven men and four women; age: 54.7 ± 10.8 years; 44.0 ± 29.0 months post-stroke) participated in the study. Patients underwent an intervention consisting of therapy using KINVIS and conventional therapeutic exercise (TherEX) for 10 days. Our originally developed KiNvisTM system was applied to induce KINVIS while watching the movement of the artificial hand. Clinical outcomes were examined to evaluate motor functions and resting-state brain functional connectivity (rsFC) by analyzing blood-oxygen-level-dependent signals measured using functional magnetic resonance imaging (fMRI). The outcomes of motor function (Fugle-Meyer Assessment, FMA) and spasticity (Modified Ashworth Scale, MAS) significantly improved after the intervention. Results: The improvement in MAS scores for the fingers and the wrist flexors reached a minimum of clinically important differences. Before the intervention, strong and significant negative correlations between the motor functions and rsFC of the inferior parietal lobule (IPL) and premotor cortex (PMd) in the unaffected hemisphere was demonstrated. These strong correlations were disappeared after the intervention. A negative and strong correlation between the motor function and rsFC of the bilateral inferior parietal sulcus (IPS) significantly changed to strong and positive correlation after the intervention. Conclusions: These results may suggest that the combination approach of KINVIS therapy and TherEX improved motor functions and decreased spasticity in the paralyzed upper extremity after stroke in the chronic phase, possibly indicating the contribution of embodied-visual stimulation. The rsFC for the interhemispheric IPS and intrahemispheric IPL and PMd may be a possible regulatory factor for improving motor function and spasticity.

S7-2: Targeted neuroplasticity following spinal cord injury

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The corticospinal tract is an important target for motor recovery after spinal cord injury (SCI) in humans. Using noninvasive electrophysiological techniques we have demonstrated the presence of reorganization in corticospinal projections targeting spinal motor neurons of muscles located close and at a distance from the injury site in individuals with chronic anatomically incomplete cervical SCI. Our physiological findings indicate that corticospinal transmission in intrinsic hand muscles change in a task-dependent manner and to a different extent in individuals taking or not taking baclofen. Changes in corticospinal transmission present after SCI also extend to the preparatory phase of upcoming movements. We have used this physiological information to develop noninvasive protocols to strengthen transmission in residual corticospinal projections and spinal cord networks in humans with incomplete SCI. Moreover, we have novel data indicating cortical connections projecting to corticospinal neurons may represent a potential alternative target for enhancing motor recovery after SCI.

Symposium 8: Novel evidence for the assessment of neuromuscular adaptations from surface electromyography

S8-1: Do we need high-density surface EMGs to assess neuromuscular adaptations?

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BACKGROUND AND AIM: The applied value of surface electromyograms (EMGs) lies in its potential to probe acute and chronic alterations of the neuromuscular system. However, whether these neuromuscular adaptations are unequivocally able to be assessed from bipolar EMGs depends on how confidently we may address the question: are we sure our surface recordings sample from the whole target muscle with negligible crosstalk from nearby sources? Here, we provide evidence showing the answer to this question depends more on the inter-electrode distance (IED) than on the number of electrodes used to sample surface EMGs (ie, on high-density recordings). METHODS: Monopolar surface

EMGs were collected with an array of 32 electrodes (5 mm IED) from biceps brachii and medial gastrocnemius of 20 healthy volunteers. Subjects were provided with visual feedback of force and asked to isometrically contract each muscle at increasing intensities--0%, 10%, 20%, 30%, 40% and 50% of their maximal force (MVC)--with each step lasting 5 s. Bipolar EMGs were obtained by differentiating pairs of monopolar signals detected for 10 progressively greater IEDs, from 5 mm to 50 mm at steps of 5 mm. Care was taken to ensure only (valid) electrodes located proximally to the biceps innervation zone and over the superficial aponeurosis of medial gastrocnemius were considered. The root mean square (RMS) amplitude of bipolar EMGs was computed using 2 s epochs; each epoch was centred around the minimum standard deviation of force for each of the six force levels and for all IEDs. Therefore, RMS values were considered to assess the discriminative power of different IEDs (two-way ANOVA with force level as repeated measures) and of the grid of electrodes (one-way ANOVA applied to RMS values averaged across consecutive, valid channels in the grid). RESULTS: A large interaction was observed between force level and IED ($F>37.02$; $P<0.01$ for both muscles). Bonferroni-corrected post hoc comparisons revealed not all IEDs could successfully discriminate EMG amplitudes between successive force levels ($\alpha=0.05$). More specifically, differences in RMS values between baseline and 10% MVC, in addition to progressively greater force levels, were observed only for IEDs greater than 30 mm and 20 mm for biceps brachii and medial gastrocnemius, respectively ($P<0.05$ for all cases). When considering RMS values for the entire grid of valid channels, statistically significant increases in EMG amplitude from baseline were observed only for force levels greater than 30% MVC for both muscles. CONCLUSIONS: These results indicate that small variations in force may not be appreciated in bipolar EMGs if detected by closely spaced electrodes. This IED-dependent sensitivity of bipolar EMGs appears to apply to muscles with fusiform and pennate architectures. Finally, sampling differential EMGs (5 mm IED) from multiple skin locations may not provide sufficient discriminative power to assess changes in force smaller than 30% MVC.

S8-2: Assessment of neuromuscular adaptations during intervention of resistance training with nutritional supplementation by high-density surface EMG

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Protein supplementation enhances gains in muscle strength following resistance training with adequate regimen. This can be explained by augmentation in muscular adaptations such as muscle hypertrophy since protein supplementation improves muscle protein synthesis after resistance training session. On the other hand, it is well known that neural adaptations such as changes in motor unit firing and recruitment patterns also contribute to gains in muscle strength following resistance training. Because neural and muscular adaptations should be associated to each other, protein supplementation may change not only muscular adaptations but also neural adaptations. Our research group attempted to investigate effect of nutritional supplementations on neural and muscular factors following resistance training. We used fish protein (Alaska pollack protein, APP) that is one of the protein sources traditionally consumed in Japan and showed more marked muscle hypertrophy comparing with casein (CAS) in rat muscle. Twenty older adults participated 8 weeks of isometric knee extension training intervention (Watanabe et al. J Gerontol A Biol Sci Med Sci, 2019). The participants were divided into two groups who took APP or CAS, respectively. Maximal muscle strength during knee extension, lower extremity muscle mass, and motor unit firing pattern of knee extensor muscle were measured at before, during, and after the intervention. Motor unit firing rate was calculated by the Convolution Kernel Compensation technique (Holobar et al. Clin Neurophysiol 2009) with high density surface EMG. Muscle strength were significantly increased in both CAS and APP after intervention, but no significant differences between the groups. Significant increases in lower extremity muscle mass during the intervention were demonstrated only for APP. Greater changes in motor unit firing pattern following intervention were represented in CAS more than in APP. These results suggest that APP ingestion preferentially induces muscular adaptation without the detectable neural adaptation in older adults. We applied same intervention to twenty young adults (Watanabe et al. in preparation). Muscle strength were significantly increased in both APP and PLA during the intervention, but no significant differences between the groups. Lower extremity muscle mass was not significantly changed during the intervention for both groups. Greater changes in motor unit firing pattern following intervention were represented in APP more than in PLA from 2week of intervention. These results suggest that APP ingestion change neural adaptation with similar adaptations in muscle strength and muscular factors in young adults and modifications of neural and muscular adaptations following resistance training by fish protein ingestion are different manners between young and older adults.

S8-3: Using HDEMG to understand the influence of low back pain on the distribution of muscle activity during a 3D dynamic task

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BACKGROUND AND AIM: Previous research using surface electromyography (EMG) has identified substantial differences in the distribution of muscle activity in individuals with low back pain (LBP). In static tasks, individuals with LBP have demonstrated less diffuse and more cranial activation of the lumbar erector spinae (ES); and shown less variation in the localization of muscle activation (centroid) during dynamic movements. However, findings have been limited to the area of investigation, in the lumbar region, and tasks have been static or one dimensional in nature. We use surface electromyography to investigate muscle activity bilaterally in both the lumbar and thoracolumbar ES during a 3D multiplanar task. METHODS: Fifteen control (CON; 26.87±11.1 years) and fourteen LBP participants (32.14±14.6 years) completed this study. The task involved cyclical lifting of a 5kg box from an anterior shelf at knee height (S1) to five anterior and lateral shelves at knee and sternal height (S2-6). Participants followed a metronome to lift the box from S1 to a peripheral shelf, rest and return to S1 before moving to the next sequential shelf. Four semi-disposable 64-channel (13x5) electrode grids were used to record muscle activity. Two prepared grids were placed end-to-end bilaterally with the lowest placed 2cm lateral to the L5 spinous process. Following data collection, the grids were virtually combined on each side, with analysis considering large left and right grids overlying both the lumbar and thoracolumbar ES. Distribution of activity was quantified from the location of the centroid in both the x (mediolateral) and y (craniocaudal) axes for each large grid; and the entropy was calculated as a measure of the heterogeneity of activation. The right-left variation in the location of the centroids for each phase of each movement was also considered. RESULTS: For all phases of all movements on both sides, systematically more cranial muscle activity was identified in the LBP group (P<0.05 for all). In both the x and y-axes there was greater variation between sides for the location of the centroid for each movement. Specifically, at the point in the movement where the participant is closest to the peripheral shelves, the CON group showed greater variation in the difference between sides for each movement, indicating movement specific strategies for muscle contractions (Y- P<0.05; X- P<0.05). Differences in distribution were supported by entropy findings, with the LBP group showing lower contraction homogeneity across the grids (P<0.05). CONCLUSIONS: These findings indicate that individuals with LBP use less varied, more cranially focussed contractions to complete multiplanar movements than CON participants. In this task LBP participants appeared to use the same region to complete all movements regardless of the direction or biomechanical advantage. These findings have relevance for the development of novel rehabilitation programmes for LBP.

S8-4: Neuromuscular adaptations following exercise-induced muscle damage

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BACKGROUND AND AIM: The surface electromyography has been used as the standard technique to investigate the neuromuscular adjustments following exercise-induced muscle damage (EIMD) [1]. There are however many factors that influence the interpretation of changes in electromyograms (EMGs) amplitude in terms of muscle activation, such as the placement and orientation of electrodes [2]. Indeed, the alterations of EMGs variables after EIMD are affected by the proximo-distal location of bipolar electrodes [3]. Therefore, here we collected surface EMGs from multiple biceps brachii regions during the supramaximal electrical stimulation of musculocutaneous nerve to assess the local muscle adaptations resulting from EIMD. METHODS: Ten healthy, male subjects were submitted to following measures conducted immediately before and four consecutive days after 3x10 eccentric elbow flexions: (i) perceived soreness of right elbow flexors during passive stretching; (ii) acquisition of ultrasound images proximally and distally from biceps; (iii) high-density recordings (64 electrodes) from biceps while 10 supramaximal pulses were applied transcutaneously to the musculocutaneous nerve; (iv) two isometric, elbow flexion maximal voluntary contractions (MVC) on a dynamometer. M-wave peak-to-peak amplitude was computed for each of the 59 single-differential channels, providing EMG images for the biceps brachii muscle. The innervation zone (IZ) longitudinal location, the number of electrodes detecting the largest M waves (segmented channels; [4]) and their relative longitudinal position were assessed for each amplitude map to characterize EIMD induced changes on M waves. RESULTS: The perceived muscle soreness increased with respect to baseline at 24, 48, 72 and 96 h after EIMD (P<0.004), while the MVC peak torque significantly decreased at 24, 48, 72 and 96 h after EIMD (P<0.001). The echo intensity of ultrasound images increased from 48 to 96 h with respect to baseline for both proximal and distal regions (P<0.001), while no differences were observed among regions at any time (P=0.136). No time effect was observed for the IZ location (P=0.283). The number of segmented channels significantly decreased and the longitudinal coordinate of the centroid shifted towards the distal region of the muscle at 24, 48 and 72 h after EIMD (P<0.032 in both cases).

CONCLUSIONS: The amplitude distribution of M waves changed consistently in the proximal biceps brachii region up to four days after EIMD. Our results therefore suggest that EIMD effects on muscle excitation should not be assessed with EMGs collected from a single muscle region. In addition, here we demonstrated the potential of EMG imaging to assess both spatial and temporal effects of EIMD on muscle function. REFERENCES: [1] Semmler 2014; Acta Physiologica 210:754-67. [2] Farina 2006; Exerc Sport Sci Rev 34(3):121-27. [3] Piitulainen et al. 2009; Muscle Nerve 40(4):617-25. [4] Vieira et al., 2010; J Biomech 43(11):2149-5

S8-5: Assessing adaptations at the motor unit level elicited by neurological diseases

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BACKGROUND AND AIM: Motor unit (MU) recruitment and firing is the basis of voluntary movement and motor control. However, this aspect of the pathophysiology of neurological diseases has not drawn much attention, although it has the potential to distinguish and monitor diseases. Charcot-Marie-Tooth disease (CMT) is a group of inherited sensory and motor neuropathies accompanied by distal muscle atrophy, weakness, and sensory loss. Among many CMT subtypes classified by over 80 associated genes, CMT type 1A (CMT1A) caused by a duplication of the PMP22 gene is the most common subtype. In the clinical trials in CMT1A, the lack of sensitive biomarkers is thought to be one of the factors that led to failures of previous clinical trials. It would be beneficial for CMT1A patients to demonstrate that neurophysiological indices obtained by non-invasive methods could be sensitive biomarkers. As such, we conducted exploratory studies to investigate potential multi-channel surface-electromyography (SEMG) parameters. METHODS: This study included 17 patients with CMT1A and 21 healthy controls. Multi-channel SEMG recording was performed on the right vastus lateralis muscle during ramp contraction from 0 to 30% of maximal voluntary contraction (MVC) and sustained contraction at 10% of MVC for 120 seconds in isometric knee extension. After recording, decomposition analysis were performed, and instantaneous firing rates (IFRs) of individual identified MUs was calculated. In CMT1A patients, follow-up measurements were performed one year after the baseline. Disease severity score (CMT neuropathy score (CMTNS)) was also measured at each visit in CMT1A patients. Comparison of clinical variables and IFRs between CMT1A patients and controls at the baseline and between at the baseline and one year after the baseline in CMT1A patients was performed. RESULTS: There was no difference in MVC between controls and CMT1A patients (28.9 kg vs. 30.1 kg, $p = 0.70$). In the ramp-up contraction, IFRs of MUs recruited at <10% of MVC were lower at all levels of the force (10%, 15%, 20%, 25% of MVC) in CMT1A group than controls. Also in the sustained isometric contraction, IFRs recruited at <10% of MVC were lower at 10, 60, and 110 sec. There was no difference in the pattern of IFR change during tasks between CMT1A patients and controls. Additionally, no longitudinal change over one year in IFRs was observed, whereas CMTNS increased over one year. CONCLUSIONS: Patients with CMT1A demonstrated significantly lower firing rates of individual MUs during voluntary contraction than controls. Increased individual MU action potential due to axonal loss followed by reinnervation may affect firing rates of MUs. Also, there was no longitudinal change in IFRs in CMT1A patients whereas disease severity changes. More sensitive MU firing parameters reflecting the severity of axonal loss should be explored in a larger cohort.

S8-6: Understanding regional activation within the lumbar extensors using high-density electromyography

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BACKGROUND AND AIM: Surface electromyography (EMG) is often used to estimate the neuromuscular activation of the lumbar extensor muscles. As the lumbar extensors comprise several muscles with different mechanical actions, it is necessary to precisely localize which muscle region generates the electrical activity to correctly characterize muscle activation patterns. As the spatial distribution of surface EMG amplitude depends on the location of the active muscle fibers under the electrodes, high-density electromyography (HDsEMG) has been used to characterize regional activation of the lumbar extensors in several studies (1). This symposium presentation will focus on understanding the association between regional activation of the lumbar extensors and variations in spatial distribution of HDsEMG amplitude, and whether the lumbar extensors are activated regionally in response to postural perturbations and in daily-living activities. METHODS: To understand how the activation of individual lumbar muscles contributes to the HDsEMG amplitude distribution, we concurrently measured the electrical activity from the longissimus (cranial and caudal portions) and superficial multifidus using selective fine-wire electrodes, and from the lumbar extensor muscles with HDsEMG during an isometric task. To elicit postural perturbations of vestibular origin, electrical vestibular stimulation was applied bilaterally over the mastoid processes while participants stood facing forward (which resulted in a medio-lateral whole-body perturbation), or with their head turned left (antero-posterior- whole-body perturbation). RESULTS: For each indwelling recording, cross-correlation analyses between intramuscular and HDsEMG recordings revealed correlation values larger than 0.25 only for HDsEMG channels in proximity of the indwelling recording (approximately 16 mm). Electrical vestibular stimulation applied while facing forward resulted in preferential response of the longissimus over the multifidus in the indwelling recordings. Similarly, responses were located more laterally in the HDsEMG while facing forward compared to the head-turned condition. Preliminary data also demonstrate different cranio-caudal spatial distributions of EMG amplitude in tasks such as arm raise, gait, sit-to-stand and forward bend. CONCLUSIONS: These studies indicate that changes in the relative activation of cranial longissimus, caudal longissimus and superficial multifidus can be observed as cranio-caudal or medio-lateral changes in spatial distribution of HDsEMG amplitude. Regional activation of the lumbar extensors can also be observed during daily-living activities. Altogether, the studies presented in this symposium presentation confirm that regional activation of individual lumbar extensor muscles can be observed in voluntary and reflexive tasks, and that HDsEMG is an appropriate tool to investigate these regional variations in activation. 1. Falla and Gallina, JEK 2020.

Symposium 9: How to promote EMG in clinical and sports settings

S9-1: What is spasticity? Contribution of sEMG to an ongoing discussion

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WHAT IS SPASTICITY? Spasticity is a term that is used in various meanings by clinicians and researchers. The problem is not only the lack of a generally accepted definition, but also the lack of methods capable for assessing spasticity. However, knowledge about the occurrence and the level of spasticity is essential for a patient tailored therapy. The most common definition of spasticity goes back to Lance: "spasticity is a motor disorder characterized by a velocity-dependent increase in tonic stretch reflexes ...as one component of the upper motor neuron syndrome" and does "not include impaired voluntary movement and an abnormal posture". The aim of this paper is not to introduce a new definition of spasticity, but to show how sEMG can help to identify, quantify and differentiate spasticity from other symptoms. SPASTICITY AND MOTOR CONTROL Little is known about the influence of spasticity on the activation of individual motor units (MUs). This is due to the fact that upper motor neuron syndrome is often associated with both spasticity and weakness. The combination of electrode arrays and spatial filters enables the non-invasive detection of single MU activity even during maximum voluntary contraction. Studies that have applied this sEMG method to patients with clinical signs of spasticity and patients without any sign of spasticity have demonstrated that a symptom of spasticity is a reduced firing rate with very low variability. SEMG FOR THE ASSESSMENT OF SPASTICITY Following Lance's definition, the tonic stretch reflex should be the primary focus to distinguish spasticity from other symptoms. sEMG has consequently been used to investigate the muscles response to stretch. It has been demonstrated that sEMG provides the easiest and most reliable way of determining the stretch reflex threshold. A more detailed assessment of spasticity becomes possible when sEMG is combined with biomechanical measurements of stretch velocity and torque. This allows both the quantification of spasticity and the monitoring of the therapy outcome. More recent approaches using sEMG take advantage of the relationship between spasticity and the dependence of the tonic stretch reflex on velocity to quantify spasticity even during free movements. SEMG IN DISORDERS ACCOMPANIED BY SPASTICITY It is beyond controversy that sEMG is an adequate tool to study muscular coordination during freely performed movements. Many studies prove the significance of understanding muscular coordination in the treatment of patients with disorders accompanied by spasticity. The most recent and promising approach is the extraction of sEMG primitive synergies. However, in general these attempts do not distinguish between spasticity and other symptoms like dystonia, rigidity or voluntary activation needed to compensate weakness. CONCLUSION sEMG has the potential to identify, quantify and differentiate spasticity from other conditions what is essential for clinical management of the patients.

S9-2: Theta-band EMG in Parkinson's disease - effect of long-term treatment with T-PEMF

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BACKGROUND AND AIM: Parkinson's disease (PD) is an asymmetric neurologic disease. Motor neuron activity in PD is characterized by reduced signal complexity and increased intermuscular coherence (1). Furthermore, EMG is characterized by a regularly oscillating muscle activation pattern and/or alternating EMG bursts which may result in tremor (approx. 5-7 Hz) if the internal torque exceeds the external torque. The aim was to further characterize Parkinson EMG and to study the effect of long-term treatment with bipolar transcranial pulsed electromagnetic stimulation (T-PEMF) on theta-band EMG. Positive effect of short-term treatment with T-PEMF (8-weeks) on muscle contraction speed in mildly affected patients has been indicated recently (2). METHODS: 22 patients with idiopathic PD (14 T-PEMF (66.6 yrs., UPDRS: 46.4, disease duration 6.2 yrs.), 8 PD-control (70.5 yrs., UPDRS 35.3, disease duration 5.3 yrs.) performed a postural task (3x1min) in a sitting position with the arms extended, horizontal and parallel while counting backwards in steps of two. Most and least affected side were identified clinically. A healthy reference group (n=5) participated to obtain reference values. The T-PEMF group received three 8-week periods, separated by two one-week pauses, of daily treatment with T-PEMF (amp. +/- 50 V, dur. 3ms, freq. 55Hz), (Re5, Denmark). Bipolar surface EMG (Marq-Medical, Denmark) was recorded bilaterally from wrist/finger extensor and the wrist flexor muscles during the postural task at baseline, week 17 and week 27. EMG power spectrum (FFT) was calculated, and power in the theta-band (4-8 Hz) was calculated and expressed as % of total power between 0.1-100 Hz. RESULTS: The PD patients had significantly higher levels of relative theta-band power in the most affected side (extensor: 13.7%, flexor: 25.8%) compared to the least affected side (ext: 6.0%, flex: 5.9%). The theta-band values in the most affected side were significantly higher than healthy reference values (ext: 7.4%, flex: 8.7%) at baseline. Thus, the relative theta-band power is sensitive to PD and even to disease severity. Long-term treatment (3x8 weeks) with T-PEMF decreased relative theta-band power in the most affected side to a level that did not differ from the healthy reference level (ext: p=0.115, flex: p= 0.168) whereas the PD-control group was still elevated compared to the healthy reference level (ext: p=0.029, flex: p= 0.015). CONCLUSION: Relative theta-band power is sensitive to PD and disease severity. Long-term treatment with T-PEMF seems to change muscle activation towards healthy values. 1: Flood MW, Jensen BR, Malling, AS, Lowery, MM. Increased EMG intermuscular coherence and reduced signal complexity in Parkinson's disease. Clin. Neurophys. 130:259-269 (2019). 2: Malling ASB, Morberg BM, Wermuth L, Gredal O, Bech P, Jensen BR. Effect of transcranial pulsed electromagnetic fields (T-PEMF) on functional rate of force development and movement speed in persons with Parkinson's disease: A randomized clinical trial. PLOS-one 13(9) (2018).

S9-3: How to promote and facilitate the accurate use of EMG for clinicians: The CEDE initiative

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Electromyography (EMG) can provide useful information for decision-making regarding rehabilitation and training for individuals with a range of clinical conditions and to enhance sport/physical activity performance. However, the accuracy and utility of information provided by EMG depends on how it is applied, analysed and interpreted. There are many potential pitfalls, and many examples where information provided by EMG is compromised by inaccurate selection of recording parameters (e.g., electrode type), inaccurate processing of data (e.g., filtering, normalisation), and inaccurate interpretation (e.g., invalid comparisons). There are several major challenges for accurate application of EMG. First, there is an extensive literature that has tested the impact of various technical aspects of EMG and distillation of this extent of information is difficult. Second, not all issues related to EMG application have been tested empirically, and there are some differences of opinion. Third, some key guidelines, such as the "ISEK EMG reporting guidelines" are somewhat generic and do not consider that parameters other than those recommended can be more appropriate in specific experimental or clinical contexts. Several important resources are available to guide use of EMG, such as the SEMIAN project, but a gap remains regarding clear guidance regarding selection of the most appropriate methods to design an application of EMG to meet the requirements of a specific context. The Consensus for Experimental Design in EMG (CEDE) project (1) aims to present a series of matrices to provide clear consensus-driven recommendations for the methods that are best to use to answer specific questions in specific contexts. The project draws on the experience of an international group of experts in EMG. To date, two matrices have been published, one dealing with "electrode selection" (2) and the other dealing with "amplitude normalisation" (3). This presentation will discuss the CEDE project, implications from the first 2 matrices, and plans for future matrices. References (1) Hodges, P. W. (2020). Editorial: Consensus for Experimental Design in Electromyography (CEDE) project. J Electromyogr Kinesiol, 50, 102343. doi:10.1016/j.jelekin.2019.07.013 (2) Besomi, M., Hodges, P. W., Van Dieen, J., Carson, R. G., Clancy, E. A., Disselhorst-Klug, C., Holobar, A., Hug, F., Kiernan, M. C., Lowery, M., McGill, K., Merletti, R., Perreault, E., Sogaard, K., Tucker, K., Besier, T., Enoka, R., Falla, D., Farina, D., Gandevia, S., Rothwell, J. C., Vicenzino, B., Wrigley, T. (2019). Consensus for experimental design in electromyography (CEDE) project: Electrode selection matrix. J Electromyogr Kinesiol, 48, 128-144. doi:10.1016/j.jelekin.2019.07.008 (3) Besomi, M., Hodges, P. W., Clancy, E. A., Van Dieen, J., Hug, F., Lowery, M., . . . Tucker, K. (2020). Consensus for experimental design in electromyography (CEDE) project: Amplitude normalization matrix. J Electromyogr Kinesiol, 53, 102438. doi:10.1016/j.jelekin.2020.102438

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