S.1: Estimating Mechanical Behavior of Skeletal Muscles Using Imaging and Modeling Modalities

S1.1: Skeletal Muscle in vivo: Unraveling Mechanical Behavior and Detecting Changes using Ultrasound Shear Wave Elastography

Filiz Ates, University of Stuttgart; Justus Marquetand, Department of neural dynamics and Magnetoencephalography, University of Tuebingen; Benedict Kleiser, Hertie-Institute for Clinical Brain Research, University of Tübingen, Tübingen, Germany; Manuela Zimmer, University of Stuttgart

BACKGROUND AND AIMThe mechanical behavior of muscles determines joint function and human movement. Characterizing muscle capacity and the length range of active force production in vivo is crucial for monitoring muscular changes. Ultrasound shear wave elastography (SWE), developed to assess local mechanical properties by measuring the shear wave propagation velocity within a tissue, emerges as a promising non-invasive approach in skeletal muscle mechanics [e.g. 1]. In this study, we explored the potential of SWE in detecting age-related and disease-induced muscular changes, contributing to a comprehensive understanding of muscle behavior.METHODSBiceps brachii muscle (BB) of healthy young (n=14; age: 28.1±5.1 years) [2] and older individuals (n=14;68.7±5.1 years) [3], and patients with myasthenia gravis (MG) (n=11; 47.6±15.7 years) [4] and facioscapulohumeral muscular dystrophy (FSHD) (n=8; 42.1±14.0 years) were studied during rest and isometric contractions at five elbow angles. SWE, electromyography, and joint moment were recorded simultaneously.RESULTSIn the passive condition (Fig. 1A), the BB elastic modulus was significantly higher in the older and MG groups compared to the young group (e.g. up to 52.6% for the older group) [3,4]. However, there were no significant differences in the FSHD group. Substantial changes were observed in the exponential characteristics of the passive elastic modulus vs elbow angle curve due to aging and MG.In the active condition, the older (25.1%), MG (26.5%), and FSHD (15.8%) groups were slightly but significantly weaker in generating elbow moments compared to the young individuals. In comparison to the young group, the BB elastic modulus measured from the older (20.3%) and FSHD (20.4%) groups were significantly lower at 25% MVC, while the MG group was 8.9% lower at 75% MVC (Fig. 1B). CONCLUSIONSOur findings suggest that SWE is capable of detecting changes in BB muscle mechanics, holding promise for monitoring these changes in various settings, such as assessing muscles at different joint positions during rest or higher-level activities for MG, or low-level activities for aging and FSHD within community settings.While passive and active behavior of muscles deduced from SWE measurements offers insights into understanding muscular adaptation, it falls short of elucidating the underlying mechanism. To harness this information as an index of muscle force, it is imperative to develop muscle models for both healthy and diseased conditions. Additionally, the validation of these models will be a crucial step forward. These aspects will be further explored, laying the groundwork for future research in the field.REFERENCES[1] Nordez A. & Hug F. J Appl Physiol 108(5), 1389-1394, 2010[2] Zimmer M. et al., J. Mech.Behav. Biomed. Mat. 137:105543, 2023[3] Ates F. et al., Nature Scientific Reports, 13(1):20062, 2023[4] Zimmer M. et al., Diagnostics, 13(6), 1108,

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S1.2: Image based model generation and optimisation for the human Achilles tendon

Alessia Furnaro, KU Leuven; Benedicte Vanwanseele, KU Leuven; Vickie Shm, University of Auckland

Background and Aim: The Achilles tendon is the largest and strongest tendon in the human body and plays a crucial role in human locomotion. Studies have shown that physical activity increases the cross-sectional area of a tendon, and this remodelling is driven by tendon cells called tenocytes. These cells are mechanosensitive in that they 'feel' the forces applied during daily activities and respond accordingly. However, the way that forces are transmitted from the body to the tenocytes is dependent on the intricate structures of tendon tissues, which modulate the force either in beneficial or detrimental ways. To truly understand Achilles tendon health in the context of degeneration and injury, it is vital to understand the tissue structure and its deformation patterns during activities of daily living.Interestingly, most Achilles tendon injuries are usually preceded by age-related degenerative changes in the tendon structure. This indicates that subtle changes in tissue microstructure from degeneration may lead to more severe tissue damage or failures. Since Achilles tendon structure is poorly understood in general, our understanding of the factors that drive age- or injury-related degenerative changes is still very limited.Methods: One intriguing feature of the Achilles tendon is that it is actuated by three muscles—the medial gastrocnemius, lateral gastrocnemius, and soleus. Bundles of tendon fascicles emanate from each of these muscles, all of these bundles fusing to form a single tendon. Although they are tightly fused, the fascicle bundles arising from these muscles are distinguishable units called subtendons.In recent years, the structure and function of these subtendons have received much attention, but this work has mainly involved tissue dissection of cadavers. Although they provided valuable insight into the tissue structure, it is still unknown how these three subtendons in the Achilles interact under physiological loading conditions and what role they play in tendon degeneration. Computational analysis can provide a solution to this problem as one can simulate how different loading conditions can affect tendon deformation patterns, hence might lead to tendon degeneration. Therefore, we have developed a robust pipeline that generates subject-specific finite element models of the Achilles tendon using 3D ultrasound images and speckle tracking and applied to both healthy and tendinopathy patients to identify the role of various rehabilitation exercises in tendon load transfer and healing.Results: Our FE models show that degeneration and injury patterns are subject-specific, highlighting the need to include these factors in modelling studies. In particular, the subject-specific loading and the tendon geometry play a crucial role in load transfer and subsequent tendon healing from rehabilitation exercises.Conclusion: Our subject-specific FE models incorporating subtendon structures showed how strain is developed within the tendon during various rehabilitation exercises and which exercises are likely to induce tissue regeneration, providing insights into intricate structure/function relationships in the human Achilles tendon.

S1.3: Muscular connective tissues: do they only provide protective packaging, or are a determinant for muscle's active force production? Finite element and imaging analyses

Can Yucesoy, Bogazici University

Skeletal muscle is the motor for joint movement. It is comprised of force-producing components i.e., sarcomeres and protective packaging structures i.e., connective tissues. In terms of skeletal muscle mechanics, it is clear that the sarcomeres are responsible for active force production in a contracting muscle and the connective tissues are ascribable for the muscle's passive resistance to stretch. However, extrapolating this to a truly independent functioning of these two domains, hence implicitly making a linear system assumption in which the contributions of the sarcomeres and connective tissues to the muscle force can be superposed to establish muscle total force may be naïve. Or more directly speaking, assuming that no mechanical interaction occurs between these domains may not be comprehensive. In contrast, a unique consideration is to ascribe muscle related connective tissues a role in contractile force production in the active state. This is viable via muscle fibers' and intramuscular connective tissues' mechanical linkages along the full peripheral lengths of muscle fibers and taking into account the concept of myofascial loads. Also considering that connective tissues of different muscles are interconnected at the muscle belly (e.g., via neurovascular tracts and compartmental tissues), muscle relative position changes occurring during joint movement will stretch muscle related connective tissues leading to myofascial loads to develop. These loads acting along the length of muscle fibers can through the mentioned connectivity reach muscle fibrils and take part in the mechanical equilibrium that determines sarcomeres' lengths, which is the key determinant of sarcomere function. Therefore, a mechanical mechanism for muscle related connective tissues to indeed play a role in muscle force production in the active state is plausible.Animal experiments show unequal muscle forces measured at both ends of a muscle or changes in its muscle length-force characteristics in different experimental conditions despite the fact that identical measurements done on the target muscle. These findings do indicate that the mechanical mechanism described above must be effective. However, in animal experiments, there is no measurement done that can reveal how the forces measured at the tendons is produced. Yet, this can be done via a coupled finite element modeling, which is designed in a way to take mechanical interactions between muscle fiber and connective tissue domains into account. In addition, although it provides only a kinematic analysis, using magnetic resonance imaging (to calculate tissue strains) and diffusion tensor imaging (to determine along muscle fiber direction) techniques combined (to calculate the local length changes along muscle fibers) how this mechanical mechanism can manipulate sarcomere lengths also in human muscles, in vivo can be exemplified. The talk will describe this mechanism and show example cases illustrating effects of surgery, botulinum toxin type-A, titin's role and elastic therapeutic taping using finite element modeling and imaging.ReferencesYucesoy, CA., Exercise Sports Sci Rev 38, 128-134,2010Pamuk, U., Cankaya, OA. and Yucesoy, CA., Frontiers in Physiology 11, 789, 2020Cankaya, OA. and Yucesoy, CA., J Biomech 116, 110197, 2021Karakuzu et al., J Biomech 57, 69-78, 2017Yildiz, S., Arpak, A. and Yucesoy, CA., J Biomech 160, 111816, 2023Turkoglu, AN, Huijing, PA. andYucesoy, CA., J Biomech 47 (7), 1565-1571, 2014Yucesoy, CA., Koopman,BH.,Grootenboer,HJ. andHuijing,PA.Biomechanics andModeling inMechanobiology 7, 175-189, 2008

S1.4: Skeletal muscle architecture in 3D: insights from in vivo measurement with 3D ultrasonography and diffusion tensor MR imaging

Yasuo Kawakami, Waseda University

Among modalities to visualize and measure skeletal muscle architecture (fascicular/tendinous arrangements within the muscle-tendon unit),ultrasonography has often been used. Brightness-mode (B-mode) ultrasonography was first used in Japan to measure cross-sectional areas of skeletal muscles by Ikai and Fukunaga (1968) then the thickness of muscles as a measure of size (e.g., Weiss and Clark, 1985). The turning point of ultrasonography was when an ultrasonic probe was placed on the skin in a longitudinal direction of the underlying muscle, to visualize fascicular paths for the measurement of pennation angle and fascicle length (Kawakami et al 1993, 1998). There is particular advantage of ultrasonography in that it enables measurement of fascicle behavior in vivo, real-time, during movements (e.g., Kawakami et al. 2002).The disadvantage of ultrasonography however is the relatively limited scan area, and two-dimensional, planar information of fascicles and tendinous structures which in reality are three-dimensional. These drawbacks can be at least partly solved by a three-dimensional ultrasound system, in which multiple ultrasound images are reconstructed three-dimensionally (Kawakami et al 2000). But one issue with this, is that for the analysis of fascicles of interest, a plane must be cut out of the reconstructed volume of the muscle, i.e., the analysis is two dimensional.A recently emerging technique to visualize and analyze fascicle architecture along and across the whole human muscles in vivo, is the magnetic resonance diffusion tensor imaging (DTI) and tractography (Takahashi et al. 2022). This technique is based on the anisotropic diffusion of water molecules along the fascicular path, and visualizing the path in a three-dimensional space. We showed fascicle's architectural variation in three dimensions which was related with the muscle size. We also demonstrated fascicle rotation in the three-dimensional space that is associated with the passive gearing, enhancing muscle belly elongation (Takahashi et al. 2023). While there are issues and challenges to overcome with this methodology (inability to observe real-time fascicular dynamics for instance), but it has potential to substantially broaden the perspective on human muscle mechanics.In the symposium, the above findings will be reviewed to discuss insights intoskeletal muscle architecture in vivo, in three-dimensional space.ReferencesIkai, M., Fukunaga, T. Intern. Zeitsch. f. Angew. Physiol., Einschl. Arbeitsphysiol. 26: 26-32, 1968.Weiss, L. W. and Clark, F. C. Phys. Ther. 65; 477-481, 1985.Kawakami, Y., Abe, T., Fukunaga, T. J. Appl. Physiol. 74: 2740-2744, 1993.Kawakami, Y., Ichinose, Y., Fukunaga, T. J. Appl. Physiol., 85: 398-404, 1998.Kawakami, Y., Muraoka, T., Ito, S., Kanehisa, H., Fukunaga, T. J. Physiol., 540: 635-646, 2002.Kawakami, Y., Ichinose, Y., Kubo, K., Ito, M., Fukunaga, T. J. Appl. Biomech. 16: 88-97, 2000.Takahashi, K., Shiotani, H., Evangelidis, P. E., Sado, N., Kawakami, Y. J. Anat. 241: 1324-1335, 2022.Takahashi, K., Shiotani, H., Evangelidis, P. E., Sado, N., Kawakami, Y. Med. Sci. Sports Exerc. 55: 2035-2044, 2023.

S1.5: Probing muscle and connective tissue structure in vivo with combined advanced MRI and computational modeling

Geoffrey Handsfield, University of North Carolina

BACKGROUND AND AIMSkeletal muscle, fascia, aponeurosis, and tendon are the tissues involved in force generation and transmission. Much prior study of biomechanical force transmission focused on skeletal muscle and tendon, with conventional models frequently only giving tacit study to the aponeurosis, and fascia tissue often being absent from models altogether. Regarding fascia, it likely contributes significantly to the forces produced in the muscular system [1-3]. The inclusion of more high-fidelity connective tissue structures in computational models will benefit our understanding in the future. To undertake this challenge, imaging and modeling techniques may be leveraged to create high-fidelity image based models of skeletal muscle, fascia, aponeurosis, and tendon. In this work, I present some of that work and the resulting models and results from this endeavor.METHODSWe optimized dual-echo UTE (ultrashort echo time) MRI sequences [5,6] to image human fascia, aponeurosis, and tendon in vivo.Using a sub-millimeter resolution (0.7 x 0.7 mm2) and a slice thickness of 4mm, we resolved pixels containing deep fascia and aponeurosis, which have thicknesses on the order of 1.5-2 mm [4]. Longer echo times (TE = 2-10ms) captured skeletal muscle. Diffusion tensor imaging (DTI) was used to determine muscle fiber architecture so as to distinguish between aponeurosis and fascia. Using these protocols, we imaged the thigh and calf region of thirty adult participants on a 3T MRI scanner. Following image acquisition, segmentation was performed for deep fascia and lower limb muscles using ITK Snap software on axial images. Finite element models were developed from these image sets of a muscle-fascia system. Fiber directions were incorporated using data from DTIRESULTSFascia thickness varied regionally on the muscle surface and spanned 1.5mm to 2.0mm, consistent with literature [4]. Our FE model of muscle and fascia (Fig. 1) explored the geometry and architecture of connective tissues interfacing with skeletal muscle, and we probed the mechanical contribution of fascia. In these models, we simulated the mechanical contribution of the presence of fascia, finding that models containing fascia presented greater longitudinal stresses on the tendon compared to models without.CONCLUSIONSUsing advanced MRI, we imaged fascia, aponeurosis, and tendon in humans in vivo and used these data to build computational models to explore force transmission. We demonstrate here novel non-Cartesian MRI that may be used to determine muscle and connective tissue architecture in vivo for new understanding and advanced model building.REFERENCESGarfin et al. (1981) J Appl Physiol 51(2):317-320.2. Maas et.al. (2010), J. Biomed. Biotechnol.5756723 .Meijer et.al. (2007), J. Electromyogr.17, 698-7074. Bhansing et al. (2015), Muscle Nerve,52:534-5395. Qian et al. (2008), Magn Reson Med.60:135-1456. Ma et al. (2017), MR in Biomed.30: 3709.

S.2: Characterizing and targeting muscle stiffness to improve treatment and rehabilitation

S2.1: Exploring the dynamics of in vivo muscle shape change: integrating internal properties and the external environment

Nikki Kelp, University of Queensland; Taylor Dick, University of Queensland

BACKGROUND AND AIMFor centuries we have known that muscles bulge during a contraction. More recently, we have learned that 3-dimensional muscle shape changes [1] are intimately linked to muscle fibre rotations in pennate muscles [2]. These dynamic changes in architecture enable muscle fibres to undergo different length changes and velocities than the whole muscle belly (i.e., gearing), with implications for a muscles mechanical output. Yet our understanding of muscle deformations has originated from experiments on single muscles during controlled and maximally active contractions whichfail to account for the complex mechanisms that underpin whole muscle behavior in vivo.The interplay between a muscle’s active machinery (i.e., the contracting muscle fibres that shorten and expand radially) and passive elements (i.e., the stiffness of the connective tissue within and surrounding a muscle) has been suggested to govern the dynamic gearing system of skeletal muscle [3]. However, in humans and animals, muscle's do not contract in isolation and thus should also be influenced by the contractile environment in which they are operating. To date, we have a limited understanding regarding how differences in internal muscle properties and the external contractile environment influence muscle shape change and gearing.METHODSWe have performed a series of experiments, combining B-mode ultrasound, electromyography, and other imaging modalities, to explore the influence of internal muscle properties (muscle architecture, connective tissue stiffness, intramuscular fat) and the external contractile environment (theneuromechanical behaviour of surrounding muscles) on muscle shape change and gearing in younger and older adults.RESULTSOur results have demonstrated that therelationship between muscle fibre rotation, shape change and fibre strain differs between synergists [4].We have also shown thatstiffer muscles bulge less, muscles with greater amounts of intramuscular fat undergo less fibre rotation, and muscles with greater physiological cross-sectional area operate at higher gearing—suggesting thatinternal muscle properties play an important role in mediating in vivo muscle shape change and gearing, especially during high-force contractions [5]. Our most recent work has indicated thata complex interplay between passive muscle properties and spatiotemporal patterns of muscle activation likely governs in vivomuscle deformationswhen you experimentally manipulate a muscle's neuromechanical environment.CONCLUSIONSFuture investigations to quantify in vivo 3D muscle shape changes during dynamic tasks or in populations with increased stiffness as a result ofneuromuscular disorders will yield important insights.REFERENCESZuurbier CJ & Huijing PA (1992).J Biomech,25(9), 1017-1026.Azizi E et al. (2008).PNAS,105(5), 1745-1750.Eng, CM et al. (2018). Int Comp Biol,58(2), 207-218.Kelp, NY et al (2021).J Biomech 129, 110823.Kelp, NY et al (2023).J Appl Physiol 129, 1520-1529.

S2.2: Coupled micromechanical models and experiments reveal implications of collagen organization on passive muscle tissue properties

Ridhi Sahani, Northwestern University; Silvia Blemker, University of Virginia

BACKGROUND: Increased passive stiffness contributes to muscle dysfunction across numerous disorders. The extracellular matrix (ECM) surrounding (epimuscular) and within skeletal muscle (intramuscular) is a key contributor to passive muscle properties. Collagen fibers regulate the tensile properties of the ECM and increased collagen levels are often assumed to relate to increased passive muscle stiffness. However, previous studies show that collagen quantity and stiffness do not correlate, and such assumptions simplify the complex structure of the ECM, where unique collagen arrangements are reported across muscle groups and during diseases. We posit that variations in collagen microstructure regulate passive muscle properties and developed a novel framework combining experimental measurements of tissue microstructure and mechanical properties with finite element models to examine these structure-function relationships. METHODS: The initial development, calibration, and validation of this framework focused on mdx (dystrophin null) and wildtype (WT) mouse diaphragm muscle, due to the devastating consequences of diaphragm muscle fibrosis in Duchenne muscular dystrophy. Intramuscular and epimuscular micromechanical models were developed to account for complex microstructure and predict stress within each region, and then coupled to predict bulk muscle tissue stress (Fig 1B). In vitro biaxial experiments were performed on diaphragm muscle tissue samples to measure bulk tissue stresses in various loading states and calculate along- and cross-muscle fiber stiffness for model calibration and validation (Fig 1C). Imaging measurements were collected to determine tissue microstructure to initialize the intramuscular model geometries, and to couple the intramuscular and epimuscular model predictions (Fig 1A).RESULTS: The models suggest that collagen fibers primarily align in the cross-muscle fiber direction, with ~2x greater cross-muscle fiber alignment in mdx relative to WT models. During equibiaxial lengthening, greater cross-muscle fiber stiffness was predicted in mdx (690±30 kPa) compared to WT models (568±34 kPa), resulting in greater cross-muscle fiber stresses in mdx relative to WT ECM (Fig 1D). Additionally, the distribution of collagen fibers had a greater impact on tissue stiffness than the amount of collagen.CONCLUSIONS: These findings suggest that the orientation and distribution of collagen explains anisotropic tissue properties observed in the diaphragm muscle and discrepancies between measurements of collagen amounts and tissue stiffness. We also highlight the need to consider collagen microstructure and in vivo biaxial loads sustained by specific muscles to measure relevant stiffness values and to design and test treatments. Future applications of this framework include examining how collagen microstructure influences stiffness across skeletal muscles with distinct macroscopic architectures and during additional loading states.

S2.4: Quantification and modeling of whole muscle passive mechanics

Benjamin Binder-Markey, Drexel University

Computational musculoskeletal models are helpful in predicting muscle function. Whole muscle active length-tension properties can be accurately predicted by scaling fiber and sarcomere mechanics to the whole muscle level using the muscle's architecture. However, the passive mechanical properties in mammalian muscle do not scale linearly across muscles and size scales. Thus, traditional scaling methods used within musculoskeletal models do not accurately predict whole-muscle passive mechanics. We have used a combination of experimental mouse and human data and computational modeling to identify sources contributing to the non-linear scaling of passive mechanics. We found within our mouse studies that to model muscle passive mechanical properties accurately, the model must reflect the complexity of the muscle with surrogate parameters accounting for the intramuscular connective tissue (ICT) content variance among muscles. Furthermore, we have high-resolution data of directly measured muscle properties throughout the human gracilis muscle's anatomical range taken during a free-functioning gracilis surgical transfer. These data include isometric contractile force, passive force, passive sarcomere lengths, and muscle dimensions. As we moved the limb through its anatomical range, passive sarcomere lengths increased from an average of 3.2 μm to 3.5 μm. This equates to an increase in sarcomere length of only 13%. At the same time, measured in-situ muscle-tendon unit (MTU) length increased by 24%. Additionally, the measured active isometric forces increased and then decreased as the MTU was lengthened. Thus, the sarcomeres active operating range covered both the ascending and descending limbs of the force-length curve. Indicating sarcomere lengths operate around the optimal sarcomere length of 2.7μ, requiring significant shortening when activated from the measured passive sarcomere length. The discrepancies in passive length changes of MTU and sarcomere length and active sarcomere shortening indicate that significant intermuscular compliance is required to explain the data.However, these sarcomere dynamics are not observable when using a standard Hill muscle model in which bulk muscle is in series with bulk tendon because of the stiff serial tendon. Only a more complex biomechanical model, in which a compliant parallel structure (likely again representing theICT) was added to the model, were the sarcomere length changes and muscle forces replicated.However, the precise structures these parallel elements in both the mouse and human models represent are the subject of ongoing investigations. These structural studies are required to define the ICT geometry and biomechanical properties and enable accurate predictions of the passive properties across muscles. With this understanding, we may be able to predict how following injury and disease changes in these ICT structures will affect muscle function.

S.3: Unique engineering approaches to modify neuromotor activity through human-robot intention and perception

S3.1: A new robotic rehabilitation paradigm: Controlling and embodying a detached robotic hand by synergistic torso muscle activity for limb function

Minoru Shinohara, Georgia Institute of Technology; Joshua Posen, Georgia Institute of Technology; Joshua Lee, Georgia Institute of Technology; Frank Hammond Iii, Georgia Institute of Technology

In neuromotor rehabilitation training, a voluntary effort to move the impaired limb may often not produce an intended functional movement. The frequent experience of such a mismatch between movement intention and production can negatively influence neural adaptation and training motivation. Mental practices such as motor imagery and action observation can intervene in the central nervous system without involving such a mismatch, but the mental tasks are not easy to perform or observe. We explored developing a new robotic rehabilitation paradigm to overcome these problems and facilitate neuromotor recovery of the upper limb impaired by stroke. The idea is to intervene in the central nervous activity without involving the upper limb muscles but activating the corresponding torso muscles that are synergistically involved in upper limb function. For example, to reach and grasp an object, stroke survivors would rotate the trunk inward and try to open the hand. To grasp and retrieve it, they would rotate the trunk backward and try to keep closing the hand. We incorporated these rotational synergies into the detached robotic hand system, in which a user activates the external oblique abdominal muscle to open the detached robotic hand and the latissimus dorsi muscle to close it, respectively. The user observes the opening and closing actions of the robotic hand and also listens to the modulated sounds associated with its movements. The repetition of the synergistic voluntary efforts and perceptual engagements can induce an embodiment of the detached robotic hand. This synergy-based human-robot interaction process may lead to the modulation of neuromotor activity and adaptations in the biological hand. We will introduce and discuss this unique robotic rehabilitation paradigm designed for stroke rehabilitation.Supported by NIH/NINDS (1R21NS118435-01A1)

S3.2: Intention-driven strength augmentation: integration of an intelligent upper-limb exoskeleton with soft bioelectronics and deep learning

Jinwoo Lee, Dongguk University

The decline in musculoskeletal strength due to aging and stroke significantly impacts daily tasks involving the upper extremities. To address this, we present an innovative upper-limb exoskeleton system integrated with deep learning technology to anticipate human intention for strength augmentation. Incorporating soft wearable sensors, the system gathers real-time muscle activity data to interpret the user's intended movements. Cloud-based deep learning accurately predicts four upper-limb joint motions with an impressive average accuracy of 96.2% and a rapid response rate of 500–550 ms, indicating the exoskeleton's seamless operation based solely on human intent. Furthermore, a set of soft pneumatic actuators supports these intended movements, delivering a force of 897 newtons and a displacement of 87 mm at maximum capacity. Through this intention-driven approach, the exoskeleton reduces average human muscle activity by 3.7 times compared to its unassisted counterpart, offering promising implications for mitigating age and stroke-related musculoskeletal decline.

S3.3: Developing training support technology with simultaneous visual and force feedback using pneumatic gel artificial muscles

Yuichi Kurita, Hiroshima University

BACKGROUND AND AIM:Exercise is essential for all people to improve and maintain physical performance and health. Visual, auditory, and haptic feedback are being used to motivate people to engage in physical activity and exercise. It has been shown that providing feedback during a user's exercise can positively affect not only performance, but also sense of accomplishment. Self-awareness and task-orientation in exercise produce positive effects through intrinsic motivation for physical activity.METHODS:We have developed a suit that provides force feedback assistance to the user's upper extremity. By attaching pneumatic gel muscles (PGMs) across the joints to the body, joint torque assistance can be provided by contraction of the PGMs. The prototype has two PGMs to assist wrist extension. A flexible LED band is also attached to the forearm, and the intensity of light emitted can be varied according to the contraction force of the PGMs. This allows force and vision to be controlled independently. We investigated how the perceived amount of force changed with the combination of greater or lesser force sensing intervention and greater or lesser visual display. The participants were seated in a chair with their upper arm relaxed on a desk, and when an extension force was applied to the wrist by the PGMs, the magnitude of the perceived force was investigated by a psychophysical experiment in which the force was reproduced against a force sensor in the same posture.RESULTS:Experimental results confirm that perceived force decreases when light intensity is less than the supporting force, and similarly, perceived force increases when light intensity is greater than the supporting force.CONCLUSIONSWe have conducted a study aimed at constructing a system that positively influences the human body and mind by independently controlling visual and force feedback. The training support technology with simultaneous visual and force feedback is expected to be used for exercise training and rehabilitation applications.

S.4: Enhancing physical function in aging and hospitalized populations with neuromuscular electrical stimulation

S4.1: Exploring the potential of sub-tetanic neuromuscular electrical stimulation for maintaining and improving physical function

Toshiaki Miyamoto, Kansai Medical University; Jun Umehara, Kansai Medical University; Satoshi Tagashira, Kansai Medical University; Takuya Fukushima, Kansai Medical University

In recent years, neuromuscular electrical stimulation (NMES) has been reported to maintain and improve physical function, including muscle strength, in various patient populations during hospitalization. However, due to the diversity in NMES settings, the optimal NMES protocol for maintaining and improving physical function remains unclear. Maffiuletti NA et al. have highlighted a lack of methodological considerations in the clinical application of NMES, emphasizing the need for establishing NMES protocols tailored to hospitalized patients based on their pathophysiological profiles. Generally, tetanic NMES, inducing strong muscle contractions, is considered as an alternative to resistance exercise, while sub-tetanic NMES is proposed as an alternative to aerobic exercise. Nevertheless, previous intervention studies have mainly focused on tetanic NMES, which might be insufficient for maintaining and improving physical function in hospitalized patients experiencing prolonged immobilization and the elderlies whose physical activity decreased. We have demonstrated that sub-tetanic NMES induces cardiorespiratory and metabolic responses comparable to walking, enhancing various systemic physiological responses. In this presentation, we report on the impact of sub-tetanic NMES on body composition, physical function, and biochemical responses, incorporating both past and recent data. Furthermore, we aim to deepen the discussion on the potential of sub-tetanic NMES for maintaining and improving physical function in hospitalized patients and the elderly.

S.5: enhancing physical function in aging and hospitalized populations with neuromuscular electrical stimulation

Symposium: Neuromechanical characterisation of muscles and their functional units using ultrasound imaging methods

S5.1: State-of-the-art and future perspectives

Robin Rohlén, Lund University / Imperial College London; Emma Lubel, Imperial College London; Christer Grönlund, Umeå University; Dario Farina, Imperial College London

Ultrasound imaging can be used to non-invasively assess muscle structure, musculoskeletal properties, and, more recently, neuromechanics in vivo. This technology can provide great spatial and temporal resolution, opening exciting avenues for investigating health, disease, and neural interfacing technology. This talk will build upon state-of-the-art ultrasound imaging technology and discuss future perspectives and translational capabilities of ultrasound imaging for the neuromechanical characterisation of muscle tissue.An ultrasound transducer on the skin parallel to the muscle fibres can be used to detect and analyse the muscle-tendon unit, muscle thickness, pennation angle, fascicle length, aponeuroses and muscle gearing. This is usually performed using a clinical ultrasound scanner with B-mode (grayscale) imaging, making it accessible to researchers, clinicians, etc. On the other hand, these scanners operate at relatively low frame rates and do not enable access to raw data to calculate displacement fields. These displacement fields are important for identifying transient events like the subtle displacements of muscle fibres in response to the neural discharges of a single motoneuron. Thus, for these applications, a programmable ultrasound research system is used. Moreover, the ultrasound transducer is usually placed perpendicular to the fibres to increase the identification yield.The above cannot all be done simultaneously due to probe positioning. However, it would enable the study of the musculoskeletal structure and properties along with the neuromechanical properties and motoneuron spike trains. Here, I will present the advancements in 3D imaging that could be applied and how they could further enable the study of dynamic contractions. For some translational activities, these systems and probes are too bulky, leading to the incentives for the rise of wearable systems. Finally, I will discuss the feasibility of studying neuromechanics and identifying neural spike trains using a clinical system through an innovative post-processing method. Such a method would increase the accessibility of neural information since a programmable ultrasound research system is currently needed.

S5.2: Ultrafast ultrasound decomposition into individual motor unit contributions

Emma Lubel, Imperial College London; Robin Rohlén, Lund University / Imperial College London; Dario Farina, Imperial College London

When action potentials reach the muscle fibres of a motor unit, they result in a synchronised twitch of the innervated muscle fibres. Thiscan be identified using ultrafast (high frame rate) ultrasound imaging perpendicular to the muscle fibres. The ability to detect and analyse these twitches can give insight into various neuromuscular diseases for research, diagnosis, and monitoring. Furthermore, identification of the precise times of these twitches could open avenues for neurorehabilitation and prosthesis control. Due to the high penetration depth of ultrasound, this could enable interfacing with deep muscle tissue which is currently inaccessible to alternative non-invasive techniques such as surface EMG.Recently, various methods to identify these twitches in voluntary contractions have been developed. This talk will provide a comprehensive overview of the current state of ultrafast ultrasound decomposition into individual motor unit contributions. We will discuss the evolution of these techniques and their relative merits, uses, and downfalls. First, a modified spike-triggered averaging approach will be presented. This relies on concurrent EMG recordings to provide motoneuron firing times. Using this method, motor units can be precisely located in the muscle cross-section,and their mean twitch profile can beobtained. Next, a method using spatiotemporal independent component analysis will be presented. Using this method, the same information can be derived with high repeatability. However, motoneuron firing times cannot be recovered accurately. Hence, the neural drive to the muscle cannot be estimated. Finally, convolutive blind source separation will be presented as a method for decomposing the ultrasound image series into motoneuron firing times. We show that using this method, high-accuracy motoneuron firing times can be extracted from a tissue velocity field derived from ultrafast ultrasound images. In a validation study on 10 participants, the units decomposed using ultrasound had a rate of agreement with sEMG decomposition of 87.4 ± 10.3%. Over 50% of these motoneuron spike trains had a rate of agreement of greater than 90%. Furthermore, with ultrasound, we identified units more than 3 cm below the surface of the skin. In contrast, the mean depth of the EMG detected units was approximately 4 mm. To conclude, the proposed methodology can non-invasively interface with the outer layers of the central nervous system, innervating the muscle across its full cross-section.

S5.3: Neuromechanical characterization of muscles and their functional units – The basics of ultrafast ultrasound acquisition, processing and bio-mechanical source

Christer Gronlund, Umeå University

Ultrasound imaging is an established method to study skeletal muscle tissue. It can be used to study static and dynamic structure and function on the whole-muscle level.Recently, using ultrafast ultrasound imaging, it has been demonstrated that the rapid transient mechanics involved in the contraction of the fibres of single contracting motor units, can be detected in electro-stimulated as well as in voluntary skeletal muscle contractions. The key difference between the conventional ultrasound and ultrafast ultrasound is the images per second that can be recorded (~50 vs +1000 images per second). Thus, the ultrafast imaging has potential to study the transient mechanics involved in fibre twitch tetantic contractions.The aim of this talk is to cover the basics in ultrafast ultrasound image acquisition, image reconstruction and post-processing, required to access information of the complex deformation pattern during skeletal muscle contraction. The underlying biomechanical source of motor unit contraction will be discussed in relation to the bioelectrical source which is mediated by the excitation contraction coupling, action potential and motoneuron neural discharges. The influence of the fascia and the corresponding myofascial coupling for this task will also be discussed. Moreover, a brief description will be given on opportunities and limitations of other new methods to assess skeletal muscle contraction information on the motor unit level including e.g. magnetic resonance imaging and optical imaging techniques.

S5.4: Combining US imaging and High-Density EMG: applications, potentialities, and challenges

Alberto Botter, Politecnico di Torino - LISiN; Marco Carbonaro, Politecnico di Torino; Marco Gazzoni, Politecnico di Torino; Taian Vieira, Politecnico di Torino; Giacinto Luigi Cerone, Politecnico di Torino

Neural excitation triggers electrical and mechanical responses in the muscle, involving the depolarization and subsequent shortening of muscle fibers. These dynamic processes display distinct spatiotemporal characteristics, which can be non-invasively measured using electromyography (EMG) and ultrasound (US) imaging, respectively.EMG and US can be detected with varying spatial and temporal resolutions, influencing the informative content of the recorded data. Single-channel surface EMG is conventionally used to assess the overall degree and timing of muscle excitation. By increasing the number of detecting electrodes positioned over the muscle surface (High-Density EMG), it becomes possible to access the firing properties of individual motor units, enabling the study of how the central nervous system controls the activation of motor unit populations during force production. Similarly, standard frame rate US imaging is employed to characterize muscle anatomy and its changes throughout a contraction. When detected with high frame rate devices, US has the potential to capture faster muscle tissue displacement allowing for the characterization of movements resulting from the excitation of single motor units. In this context, the combination of EMG and US emerges as a valuable tool, providing insights into both neural and mechanical variables and the way they interplay to generate force.The HDEMG-US integration has found applications in various areas of neuromuscular research. Standard frame rate US and HDEMG have been employed to: (i) investigate the association between common oscillations in motor unit spike trains and fascicle movements during constant force or force-varying contractions; (ii) non-invasively identify fasciculation potentials across a large muscle volume; (iii) study the electromechanical delay. More recently, the combination of HDEMG and US has been applied to the field of motor unit decomposition. Motor unit spike trains extracted from HDEMG were used to either enhance or validate innovative decomposition methods based on the processing of high frame rate US sequences. Additionally, quantifying architectural changes in the contracting muscle with US can enhance the tracking of motor unit action potentials during dynamic or force-varying isometric conditions. After providing an overview of these applications, this talk will focus on the technological challenges associated with the simultaneous detection of HDEMG and US from the same muscle region, with a specific emphasis on electrode technology. Possible technological solutions for the joint detection of high-quality HDEMG signals and US images will be presented, along with their advantages and disadvantages and their usability in various experimental contexts, including recordings from muscles with different sizes and architectures, during different motor tasks, and with various US techniques (e.g., 2D vs 3D imaging or panoramic US).

S5.5: Skeletal muscle ultrasound and the never-ending search for a link to function: beyond just static imaging

Martino Franchi, University of Padova; Marco Carbonaro, Politecnico di Torino; Alberto Botter, Politecnico di Torino - LISiN; Clarissa Brusco, Department of Biomedical Sciences, University of Padova

Martino V. Franchi 1, Marco Carbonaro 2, Alberto Botter 2, Clarissa M. Brusco 11Human Neuromuscular Lab, Department of Biomedical Sciences, University of Padua, Italy2LISiN, Dipartimento di Elettronica e Telecomunicazioni, Politecnico di Torino, Turin, ItalySkeletal muscle is the largest adipose tissue-free mass in humans, crucial for locomotion and metabolic health. It’s not surprising that muscle mass assessment holds importance in performance and clinical scenarios, from potential injury risks identification to the clinical diagnosis of sarcopenia or frailty. In this context, ultrasound represents an easily accessible option for examining skeletal muscle mass and its structure in-vivo.Two-dimensional ultrasound B-mode technique represents the most frequently applied technique to quantify skeletal muscle mass and evaluate architectural features to relate these parameters to muscle function in healthy, ageing, and clinical populations. The assessment of such properties is seen as fundamental to elucidate the mechanisms of how the muscle-tendon unit (MTU) functions as a whole system. In the last 15 years image quality has significantly improved and more refined methodologies, such as Extended Field of View (EFOV) and 3-D ultrasound, have been developed and implemented for the study of muscle architectural properties with the muscle relaxed or during contraction. Yet the link between MTU structure and function is still to decipher, as well as how adaptations to increased loading (exercise) or unloading (muscle disuse, physical inactivity) impact on this structure-to-function relationship.The present talk will delineate the journey from old and novel static imaging possibilities to the use of ultrasound in dynamic scenariosemployed to characterize MTU behavior throughout muscle contraction, linking these structural properties to muscle force production and its efficiency. The concept of architectural changes during contraction (MTU gearing) in different context will be explained and unpublished data related to ageing populations will be presented.Moreover, the talk willpresent the current implementations on semi-automatic and automatic (deep learning based) approaches to measure MTU properties, discussing the pros and cons of such cutting-edge methodologies. Lastly, the main fields of application and the current challenges of MTU ultrasound assessment will be critically discussed, paving the way for the subsequent talk of Prof Botter, related to the integration of ultrasound-derived properties and motor unit features assessed by high-density electromyography.

S.6: Motor unit analysis of surface EMG for precision rehabilitation: advances and challenges

S6.1: Neuro-musculoskeletal modeling for online estimation of continuous wrist movements from motor unit activities

Xu Zhang, University of Science and Technology of China; Yunfei Liu, University of Science and Technology of China; Haowen Zhao, University of Science and Technology of China

Decoding movement intentions from motor unit (MU) activities remains an ongoing challenge. The cutting-edge data-driven approaches mainly employ a "black box" for mapping MU activities into body movements nonlinearly, thus constraining our comprehension of the intricate transition mechanism from microscopic neural commands to macroscopic movements. In contrast, model-based approaches can offer a series of explicit relationships to simulate this transition process, providing a foundation for strong physiological interpretability. However, several issues persist in the application of model-based approaches for resolving MU activities, e.g., incomplete utilization and inaccurate characterization of microscopic neural commands represented by the MU activities. This study presents an innovative neuro-musculoskeletal (NMS) model driven by MU activities for online estimation of continuous wrist movements. The proposed model employs a physiological and comprehensive utilization of MU firings and waveforms, thus facilitating the localization of MUs to muscle-tendon units (MTU) as well as the computation of MU-specific neural excitations. Subsequently, the MU-specific neural excitations were integrated to form the MTU-specific neural excitations, which were then inputted into a musculoskeletal model to accomplish the joint angle estimation. A global optimization algorithm was subsequently applied to obtain the model parameters that are challenging to measure in vivo. To assess the effectiveness of this model, high-density surface electromyogram and angular data were collected from the forearms of eight subjects during their performance of wrist flexion-extension task. Two pieces of 8 × 8 electrode arrays and a motion capture system were employed for data acquisition. Following offline model calibration, online angle estimation results demonstrated a significant superiority of the proposed model over two state-of-the-art NMS models (p < 0.05), yielding the lowest normalized root mean square error (0.10 ± 0.02) and the highest determination coefficient (0.87 ± 0.06). This study provides a novel idea for the decoding of joint movements from individual MU activities. The results hold the potential to advance the development of NMS models towards the control of multiple degrees of freedom, with promising applications in the fields of motor control, biomechanics, and neuro-rehabilitation engineering.

S6.2: Muscle innervation zone estimation with surface EMG: a simulated comparison study using motor unit and overall muscle activities

Chengjun Huang, University of Health and Rehabilitation Sciences; Maoqi Chen, University of Health and Rehabilitation Sciences; Ping Zhou, University of Health and Rehabilitation Sciences

Background and Aim. Muscle innervation zones (IZs) are the site where the muscle fibers are innervated by the terminals of motor axons. Accurate estimation of muscle IZ location has important research and diagnostic value. The objective of this study was to investigate the performance of two different approaches to muscle IZ estimation using surface electrode array electromyography (EMG), based on motor unit and overall muscle activities, respectively.Methods. The study was performed by implementing a model simulating surface EMG signals. Three IZ distributions were simulated. Specifically, the first situation simulates the IZ distribution as a V-shape. The second situation simulates the IZ distribution as inclined lines with respect to muscle fiber direction. The third situation simulates that a muscle has two IZs. For each situation, electrode array surface EMG signals were simulated 10 times. Two approaches were applied and evaluated to estimate muscle IZs. The first approach was based on conventional interference surface EMG analyses. For the second approach, the simulated signals were decomposed by the progressive FastICA peel-off (PFP) method to extract multiple motor unit action potential (MUAP) trains. We then estimated individual motor unit IZ from its MUAP spatial distribution, and collectively estimated muscle IZ distribution from all extracted motor units.Results. For all the three situations, the IZ distribution estimated from decomposed motor unit activities was more consistent to the model input, compared with that derived from the interference surface EMG analysis.Conclusions. Advances in high-density surface EMG decomposition provide a useful approach to precise estimation of muscle IZ from collective individual motor unit activities, which has important value for neuromuscular investigation and clinical practice (e.g. guiding botulinum toxin injection for spasticity treatment).

S6.3: High-density surface EMG guided personalized botulinum neurotoxin injection in treating muscle spasticity

Yingchun Zhang, University of Houston

BACKGROUND AND AIM: Spasticity is commonly seen in about 1/3 of post-stroke survivors. It interacts with and amplifies other impairments, resulting in disabling consequences. Thus it imposes significant adverse impacts on patients, caregivers and society. As the first-line treatment for focal spasticity management, intramuscular botulinum neurotoxin (BoNT) injection has been proven as a relatively safe procedure; yet dose-dependent adverse effects may occur during treatment, such as excessive muscle weakness, atrophy, pain and spread blockage of off-target muscles and autonomic nerves. BoNT is a powerful inhibitor of synaptic transmission acting at neuromuscular junctions (NMJ), indicated by innervation zones (IZ). Therefore, BoNT injections directed to the proximity of NMJs can retain or even potentiate the treatment efficacy, while simultaneously minimizing dosage-dependent adverse effects. Studies have demonstrated that increasing the injection distance by 1 cm from the IZ reduces the efficacy of BoNT by 46%. Unfortunately, current IZ localization technique is based on anatomical landmarks established in healthy muscles or cadavers. It is important to note that IZ locations in spastic muscles of stroke survivors are dramatically different from those from cadaver or healthy muscles.IZs are visually identified from EMG signals collected over the skin surface using evenly spaced linear sensor arrays or 2-dimensional grids. The application of these IZ localization methods at the skin level is intrinsically limited by their low spatial resolution and sensitivity to anatomic variations in patients, largely because the poor conducting subcutaneous fat tissues impose an electric blurring/distorting effect on the surface potential distribution. However, none of previous surface EMG techniques can tackle this electric blurring/distorting issue for an accurate IZ imaging.METHODS: To bridge this technical gap, a 3-dimensional (3D) innervation zone imaging (3DIZI) technique has recently been developed by our group to image the 3D distributions of IZs in muscles from high-density surface EMG recordings. The developed 3DIZI technique has been utilized to guide BoNT injection in treating muscle spasticity in post-stroke survivors.RESULTS: Our pilot results achieved in both healthy and spastic muscle studies, and clinical trial studies have consistently demonstrated the superior IZ imaging accuracy and robustness of the 3DIZI, and its promising use in optimizing the therapeutic outcome of clinical BoNT injection. Patients (n=6) with muscle spasticity who received IZ imaging guided BoNT injections experienced superior therapeutic outcome compared to patients (n=6) who received standard ultrasound guided injections (non IZ imaging guided), evidenced by a larger and more stabilized reduction in supramaximal compound muscle action potentials (34.71±5.42% vs. 20.92±6.73%, p<0.01) and muscle activation volume (71.51±8.20% vs. 44.33±21.81%, p<0.05).CONCLUSIONS: Results demonstrated the feasibility of developing a personalized BoNT injection technique for the optimization of clinical treatment for post-stroke spasticity using the 3DIZI technique.

S.7: exoskeletons for health

S7.1: Exoskeletons for more or better physical activity?

Pascal Madeleine, Aalborg University; Cristina-Ioana Pirscoveanu, Aalborg University; Lasse S Jacobsen, Aalborg University

BACKGROUND AND AIM: Exoskeletons can make activities of daily living easier. That goes for people with movement disorders, older adults, and asymptomatic workers (1,2). Exoskeletons are wearable mechanical structures divided in two categories: active and passive exoskeletons depending on whether these are motorized or not. Still the impact of exoskeletons on activities of daily living are just poorly understood (1,3). The aim of this abstract is to review the known physiological and biomechanical effects of using exoskeletons in both able-bodied and impaired adults.METHODS: The electronic search was performed on PubMed-MEDLINE and Scopus. The search terms were combined and resulted in the following string: "exoskeleton" AND "biomechanics" AND "physiology". Additional searches were made based on the cited references of the retrieved papers. All abstracts were scrutinized, and the main findings were extracted. The studies assessed both physiological (e.g., oxygen consumption and surface electromyography) and biomechanical responses (e.g., kinetic and kinematics).RESULTS: Ninety-one and 594 studies were retrieved in PubMed-MEDLINE and Scopus, respectively. Active exoskeletons have so far almost essentially been used in laboratory settings while passive exoskeletons have been used in both laboratory and field settings. There is evidence showing that exoskeletons can for instance reduce the energy cost of walking in both able-bodied and impaired adults, improve gait pattern of elderly adults and people with cerebral palsy, and diminish the biomechanical load of workers, i.e., decreasing the level of activation of low-back and neck-shoulder muscles. Most of these studies show that exoskeletons can augment physical performance while doing activities of daily living.CONCLUSIONS: Still the present studies do not access the long-term effects of using exoskeletons and fail to demonstrate and explain how and why some people adopt such devices. This underlines the current gaps in scientific literature concerning the use of active and passive exoskeletons and their long-term impact on activities of daily living. The presentation will open the invited symposium “Exoskeletons for Health” and will be followed by presentations from Ph.D. student C.I. Pirscoveanu, Professor D. Srinivasan, and Dr K Desbrosses.Poggensee and Collins. Sci Robot6: eabf1078, 2021Theurel and Desbrosses. IISE Trans Occup Ergon Hum Factors 7:1–21.Nussbaum et al. IISE Trans Occup Ergon Hum Factors 3-4:153–162.

S7.2: The effect of wearing a hip assistive exoskeleton on walking characteristics during dual-tasking

Cristina-Ioana Pirscoveanu, Aalborg University; Ernst Albin Hansen, University College Absalon; Jesper Franch, Aalborg Univeristy; Pascal Madeleine, Aalborg University; , ; , ; , ; , ; ,

INTRODUCTION: Daily activities frequently entail undertaking multiple tasks related to mobility, cognition or decision-making which becomes increasingly difficult with age (1,2). Conventional walking aids can improve walking performance in the dual-tasking paradigms (3). Exoskeletons are a new assistive technology for the senior population (4), but the interplay between age, exoskeletons, and dual-tasking on walking characteristics remains unknown.METHODS: Twenty-two senior adults (SA) (19 females and 3 males, 72.5±4.4 years, 1.67±0.07 m and 74.2±14.2 kg) and twenty-six young adults (YA) (9 females and 17males, 26.4±3.2 years, 1.78±0.12 m and 80.7±18.7 kg) walked at their preferred speed with an exoskeleton (Exo), without (noExo), and with placebo (Sham) during two types of walking: normal walking (NW) and dual-tasking (DT). During DT, participants had to do sequential subtractions of 7 from a randomly generated start number between 490 and 499. The exoskeleton used was a bilateral hip assistive exoskeleton (aLQ, IMASEN Electrical Ltd., Aichi, Japan). The gait pattern was recorded using mocap and force plates sampled at 1000 Hz. The recordings were made in a randomized and balanced order and repeated five times. Speed, cadence, double support time (DST), step length, and three-dimensional (X – flex/extension, Y- abd/adduction, Z- int/external rotation) hip range of motion (ROM) were extracted to characterize the gait pattern.Three-way MANOVA with age (SA vs YA), device (Exo vs noEXO vs Sham), and condition (NW vs DT) were conducted (p <.05, inferred significance).RESULTS: There was a main effect of condition for cadence (F1,275=11.4, p<.01), DST (F1,275=7.9, p<.01), and speed (F1,275=9.6, p<.01). There was a main effect of age for step length (F1,275=140.9, p<.01), speed (F1,275=39.9, p<.01), DST (F1,275=21.5, p<.01), ROMx (F1,275=5.5, p=.02), and ROMz (F1,275=6.6, p=.01). There was a main effect of the device only for ROMz (F1,275=3.1, p=.02). Lower cadence was seen during DT vs NW for SA during noExo (p=.02). Increased DST was seen for SA vs. YG during DT for all devices (p<.05). Shorter step lengths occurred for SA vs YA during both conditions (NW and DT) and using all devices (Exo, noExo, Sham) (p<.01). Decreased speed was found for SA vs YA during DT (p<.01) and NW (p<.03) for all devices. Larger ROMz was found for SA for DT vs NW with Sham (p=.02).CONCLUSION: The present findings confirmed an age-related difference in gait patterns through decreased speed, shorter step length and increased DST in SA. Dual tasking and the exoskeleton did not influence the gait pattern of YG. However, the SA seemed more challenged by the DT, exemplified by decreased walking speed and increased DST. Wearing the exoskeleton mitigated the decline in gait patterns during DT of SAsuggesting that this passive assistive hip exoskeleton could be used in more challenging activities of daily living. However, further research is needed to confirm this.(1). Brustio et al. PloS one 12(7): e0181698, 2017(2). Tramontano et al. Eur J Phys Rehabil Med 53(1): 7-13, 2017(3). Miyasike-daSilva et al. Gait & posture 37(2): 287-289, 2013(4). Chen et al. J Orthop Translat20: 4-13, 2020

S7.3: Muscle activities and kinematics during a shoulder flexion with the use of a physical assistance

Kévin Desbrosses, French National Institute of Occupational Health and Safety (INRS); Mathilde Schwartz, Working Life Department, National Institute of Occupational Health and Safety (INRS); Jean Theurel, Working Life Department, National Institute of Occupational Health and Safety (INRS)

BACKGROUND AND AIM: Manual handling tasks at work can induce mechanical strain and fatigue at the shoulder level and subsequently the development of musculoskeletal disorders. Upper-limb occupational exoskeletons could assist the workers in these tasks by reducing the activity of the main muscles involved in the shoulder flexion. Nevertheless, the majority of the shoulder tendinopathies, and more particularly subacromial impingement syndrome (SIS),depends on the muscle coordination and the kinematics of the joints composing the shoulder complex, and not just on an elevated activity of the shoulder flexor muscles. It therefore appears essential to ensure that the use of a physical assistive device, by reducing the activity of agonist muscles, does not lead to unexpected consequences on the functional behavior of the shoulder. Thus, the aim of the present studywasto assess muscle activities and joint kinematics of the shoulder during an upper-limb elevation realized with and without a physical assistance.METHODS: Twenty-five participants performed shoulder flexions from 0 to 100° of arm elevation without (FREE) and with a physical assistance of 50% (A50) and 90% (A90) of the required torque by the task (50% of the maximal voluntary torque). A homemade device provided the assistance. Movement speed was set to 15°/s using an isokinetic ergometer. The EMG activity of the anterior deltoid, posterior deltoid, medial deltoid, upper trapezoid, latissimus dorsi and triceps brachiimuscles was recorded. Kinematics of the shoulder was evaluated using an optoelectronic motion capture system and the subacromial space was measured using ultrasound imagery.RESULTS: EMG activity of anterior and medial deltoid muscles was reduced for A50 and A90 compared to FREE over the whole flexion (p<0.05). EMG activity of posterior deltoid and latissimus dorsi muscles was increased for A50 and A90 from 10 to 40° of flexion (p<0.05). The scapulohumeral rhythm was modified from 10 to 30° of flexion for A50 and from 10 to 60° for A90 (p<0.05). The subacromial space was larger for A50 and A90 as compared to FREE, respectively from 10 to 50° and from 10 to 70° of flexion (p<0.05). A tendency (p=0.08) was observed for a shorter subacromial space for A50 as compared to FREE for 90° of flexion.CONCLUSIONS: Our results shown a decrease in the EMG activity of agonist muscles withthe physical assistance, confirming the potential usefulness of exoskeletons. However, the increased EMG activity of antagonist muscles demonstrated a larger co-activation. These adaptations in muscles activity with the assistance could modify the kinematics of the shoulder as indicated by the evolution of the scapulohumeral rhythm. This could be problematic, especially for this joint that requires stability to avoid a SIS. Nevertheless, the subacromial space increased with the assistance for a large part of the movement, suggesting a lower risk for a SIS. Therefore, from 10 to 90° of shoulder flexion, the use of a physical assistance could limit the muscle stress and the mechanical strain at the origin of tendinopathies. For higher arm elevations (more than 90°), the subacromial space could decrease with the assistance. Future studies appear necessary to confirm these results.

S7.4: A comparative evaluation of passive vs. powered back-support exoskeletons for assisting load carriage

Divya Srinivasan, Clemson University; Rahul Narasimhan, Clemson University; Ananya Rao, Clemson University; Jangho Park, Clemson University

BACKGROUND AND AIM: The introduction of back-support exoskeletons (BSEs) is expected to reduce the risk of overexertion injuries to the back that are common in physically demanding tasks, such as lifting and load carriage. However, BSEs can be of several types, such as passive spring-based rigid devices, soft elastic exosuits, and even powered exoskeletons. These devices have significantly different design features, support torque profiles, and interfaces with the body, hence potentially affecting a user's movement kinematics and muscle coordination strategies quite differently. The aim of this study was to characterize the biomechanical effects of a variety of BSE designs during lifting and load carriage.METHODS: Twenty-four healthy males and females, with no recent history of musculoskeletal disorders, were recruited from the local community. Participants performed a set of symmetric and asymmetric lifting and load carriage tasks in a control (no-exoskeleton condition) and using four different types of BSEs. Each BSE was set to provide a user-preferred level of assistance. Load levels and locations of load were manipulated, to realistically simulate industrially relevant tasks. Torso, hip, and knee kinematics, and muscle activity of the bilateral trunk flexors and extensors, were monitored during all tasks. Median and peak angles (from kinematic data), and median and peak amplitudes from the muscle activity data, were summarized and compared across experimental conditions.RESULTS: Preliminary results indicate that passive BSEs were associated with small but statistically significant reduction in trunk flexion angles, while no significant difference in trunk flexion angle was observed when using the powered exoskeleton, as compared to the control condition. All devices led to statistically significant reductions in trunk extensor muscle activity, as expected, however there were significant interactions between device type and task type, indicating that some devices were more effective in the asymmetric conditions than others.CONCLUSIONS: Several trade-offs between device type and task type were observed in our preliminary results, indicating that while there are many viable designs for BSEs, the optimal device choice may be best justified by the specific task characteristics, in order to maximally benefit from exoskeletons.

S.8: International Motoneuron Society: non-invasive methods to understand human motoneuron physiology in health, disease, and training

S8.1: Fatigue matters – force regulation and motor unit firing behavior in fatiguing contractions post stroke

Allison Hyngstrom, Marquette University; Zachary Kroll, Marquette University; Brian Schmit, Marquette University; Francesco Negro, Universita' degli Studi di Brescia; Matthew Durand, Medical College of Wisconsin

BACKGROUND AND AIM: Impaired firing behavior of motor units may limit motor performance during fatiguing contractions in people with chronic stroke. This study quantified stroke-related changes in estimations of common synaptic drive (CSD) and average discharge rates of motor units identified from high-density surface electromyography (HD-sEMG). METHODS: In 11 chronic stroke survivors (5 female, average age= 58±10 yrs) and 10 people without stroke (4 female, average age=62±18 yrs), HD-sEMG measurements from the vastus lateralis were made during a sub-maximal, isometric fatiguing contraction on the paretic and the dominant legs, respectfully. HD-sEMG signals were decomposed using a multichannel convolutive blind source separation algorithm (Negro et al, 2016) to identify motor units and subsequently quantify discharge rates. The instantaneous motor unit discharge rates for each participant during the first and last 10% of the contraction were smoothed (Hann window 400ms, high-pass filter 0.75 Hz) and averaged together. A principal component analysis was performed and the coefficient of variation of the first common component (CV_FCC) was calculated to provide an estimate of the fluctuations in CSD to the motor neuron pool. The coefficient of variation of torque (CV_T) was calculated to quantify the relative magnitude of force fluctuations. RESULTS: On average, task duration was shorter for the paretic leg compared to the control (288±117s vs. 342±217s) and there was a larger relative decrease in discharge rates in the stroke versus control group (18.0±8%, vs. 5.9±19%). This was accompanied by the CV_FCC and CV_DR tending to be higher for the paretic leg versus control at the beginning and the end of the contraction. There was also a larger relative increase in the paretic CV_T versus control (205±150%, vs. 128±67%). For both the stroke and control group there was a positive correlation between the change in discharge rate and task duration (stroke r2=0.44, control r2=0.54). CONCLUSIONS: Greater declines in discharge rates and increased discharge rate variability may contribute to increased paretic muscle neuromuscular fatigability and impaired sub-maximal force regulation as compared to people without stroke.

S8.2: Sex matters – biological sex and hormonal effects on estimating motoneuron properties in humans

Sophie Jenz, Northwestern University; James Beauchamp, Carnegie Mellon University; Alex Benedetto, Northwestern University; Melissa Fajardo, Northwestern Unversity; Colin Franz, Northwestern University; Tea Lulic-Kuryllo, University of Brescia; Francesco Negro, Universita' degli Studi di Brescia; CJ Heckman, Northwestern University; Greg Pearcey, Memorial University of Newfoundland

BACKGROUND AND AIM:Females have historically been excluded from research studies, due to the challenge of accounting for hormone fluctuations during the menstrual cycle in humans and the estrous cycle in other animals. Paradoxically, this is exactly why females should be studied. Their fluctuating hormones offer a fascinating model to better understand the roles and effects of these molecules in various areas of the nervous system, such as the neural control of movement. During this talk we will discuss several of our lab's studies using HDsEMG to identify mechanisms behind sex-related differences in human motor unit discharge. Sex-related differences motor unit discharge properties have been revealed in recent years, but the underlying mechanisms are unknown. A plausible mechanism that contributes to these differences is the magnitude of persistent inward currents (PICs). METHODS:Using the paired motor unit technique to quantify the discharge rate hysteresis of motor units, we've shown that estimates of PICs in human lower limbs are higher in females than males. This suggests differences in monoaminergic signaling and/or local inhibitory circuits contribute to sex-related differences in discharge patterns. PICs are facilitated by monoaminergic signaling of serotonin and norepinephrine to spinal motoneurons and constrained by local inhibitory circuits. In reduced preparations, monoaminergic signaling is affected by female sex hormones in several areas of the nervous system. Our ongoing work investigates the motor unit discharge of eumenorrheic females across the menstrual cycle in comparison to females taking oral contraception, who subsequently have attenuated levels of endogenous sex hormones. RESULTS:Preliminary data suggest that estimates of PICs are reduced when levels of estradiol are high and progesterone are low (prior to ovulation in eumenorrheic females), suggesting elevated estradiol may influence the serotonin or noradrenergic signaling to spinal motor neurons. CONCLUSIONS:These novel findings help complete our understanding of motor physiology – one that includes all humans. They also emphasize the need to incorporate sex as a biological variable in neuromuscular studies. The overall goal of this talk is to shed light on the complex interplay between sex differences, endocrine function, and motor unit discharge patterns, of which our understanding just beginning to evolve.

S8.3: Behavioural context matters – motor unit discharge behavior during isolated and synergistic finger movements

Helio Cabral, Università degli Studi di Brescia; Caterina Cosentino, Università degli Studi di Brescia; Andrea Rizzardi, Università degli Studi di Brescia; Claudio Orizio, University of Brescia; Francesco Negro, Università degli Studi di Brescia

BACKGROUND AND AIM:The movement of the fingers requires a highly coordinated interplay between the hand extrinsic and intrinsic muscles, demanding complex control by the central nervous system. While the fingers do not flex in complete isolation, the opposable thumb exhibits a high level of individuation and control. This observation implies potential differences in neural control between the flexion of fingers (fingers flexion task), the flexion of the thumb (thumb flexion task) and the synergistic flexion of fingers and thumb (grasp task). In this study,

we decomposed high-density surface electromyography (HDsEMG) signals from the hand extrinsic flexor muscles to investigate the control of motor units during these tasks.METHODS: HDsEMG signals were recorded from the extrinsic flexor muscles in 17 healthy subjects, while they performed three tasks: fingers flexion task (simultaneous flexion of the four fingers); thumb flexion task (isolated flexion of the thumb); and grasp task (synergistic flexion of the four fingers and the thumb). Tasks were performed at 5% of maximal voluntary isometric contraction. HDsEMG signals were decomposed into motor unit spike trains using a convolutive blind-source separation algorithm [1]. Motor units were tracked separately between fingers flexion and grasp tasks, and between thumb flexion and grasp tasks. Mean discharge rate of motor units and motor unit coherence within delta (1-5 Hz), alpha (5-15 Hz) and beta (15-35 Hz) bands were calculated. Linear mixed models were used to statistically compare these values between tasks.RESULTS: Results revealed significant changes in both motor unit mean discharge rate and motor unit coherence between fingers flexion, thumb flexion and grasp tasks. The grasp task showed a reduction of 0.7 ± 0.2 pps (mean ± standard error) in motor unit mean discharge rate compared to fingers flexion (P = 0.003), but an increase of 1.7 ± 0.4 pps compared to thumb flexion (P < 0.001). Due to the number of matched motor units, coherence analysis was performed only between fingers flexion and grasp tasks, revealing a significant decrease of 0.1 ± 0.03 in average z-coherence within the alpha band (P = 0.006), but not in delta or beta bands (P > 0.06 for both).CONCLUSIONS: Our findings indicate distinct neural control patterns between fingers flexion, thumb flexion and grasp contractions. Results suggest task-specific alterations in mean discharge rate of hand extrinsic flexors, with a decrease was observed between fingers flexion and grasp tasks and the opposite between thumb flexion and grasps tasks. Moreover, our study demonstrates a reduction in physiological tremor oscillations when comparing fingers flexion with synergistic grasp task.REFERENCES:[1] Negro et al., 2016.

S8.4: Training status matters – chronic training-induced plasticity of the human cortico-motoneuronal pathway

Duane Button, Memorial University of Newfoundland

BACKGROUND AND AIM:The corticospinal tract is an important pathway through which motor signals travel from the brain to the spinal cord in order to transmit voluntary motor commands to skeletal muscle. This pathway activates the motoneurones within the spinal cord and, in turn, the skeletal muscle. One way to increase the activation of this pathway is resistance training. During the acute (8-12 weeks) phase of resistance training, adaptions within the nervous system are the primary driver(s) for strength gains. In the longer term, or chronic resistance training, muscle adaptations are the primary driver(s) of strength gain. Because the acute phase of resistance training is of short duration and induces nervous system adaptation, the effects of acute resistance training on the nervous system dominates the literature. However, due to challenges involved in collecting data over long periods of time, the effect of chronic resistance training on the nervous system is rudimentary. Thus, the aim of this work was to determine the effect of chronic resistance training of thecortico-motoneuronal pathway.METHODS: There were several methods employed to illustratechronic training-induced plasticity of the human cortico-motoneuronal pathway. Motor evoked potentials (MEP) arising from transcranial magnetic stimulation (TMS), cervicomedullary motor evoked potentials (CMEP) elicited via transmastoid electrical stimulation (TMES) and maximal muscle compound action potentials (Mmax) elicited by Erb's point electrical stimulation were used to assess supraspinal, spinal and muscle excitability, respectively.Paired-pulse TMS experiments were also employed to further examine changes in 'supraspinal' excitability. More specifically, paired-pulse stimulation was used to determine changes in motor cortex neurons and inhibitory networks via short-interval intracortical inhibition (SICI).RESULTS:Chronic resistance training alters thecortico-motoneuronal pathway of the biceps brachii. MEP and CMEP amplitudes and SICI of the biceps brachii were different between non-resistance trained and chronically trained groups indicating nervous system changes both supraspinally (i.e. cortical neurons) and spinally (i.e. motoneurones). MEP and CMEP amplitudes of the biceps brachii were altered at higher contraction intensities (>50% of maximum voluntary contraction). It was argued that changes in MEP and CMEP amplitudes were due to altered motoneurone excitability. Furthermore, active motor threshold (i.e TMS intensity required to induce a MEP) and SICI of the biceps brachii were reduced during 25 and 40% MVC of the elbow flexors in the chronic-resistance trained individuals.CONCLUSIONS:There are few studies detailing the effects of chronic-resistance training on thecortico-motoneuronal pathway. Plasticity along thecortico-motoneuronal pathwayto the biceps brachii has been shown tooccur supraspinally and spinally. This plasticity most likely includes changes in the intra-cortical circuitry leading to facilitation (i.e. reduced inhibition) of the upper motoneurons and greater firing frequencies of the motor units.

S8.5: Intensity matters – training and ageing-induced adaptations in the discharge behaviour of human motor unit populations

Jakob Škarabot, Loughborough University; Christopher D Connelly, Loughborough University; Haydn Thomason, Loughborough University; Tamara Valenčič, Loughborough University; James Beauchamp, Carnegie Mellon University; Greg Pearcey, Memorial University of Newfoundland

BACKGROUND AND AIM: Muscle contraction results from a non-linear transformation of motor commands via motor units (MUs). Ionotropic inputs provide excitation and inhibition whilst neuromodulatory inputs facilitate dendritic persistent inward currents (PICs) in motoneurons that generate non-linear MU discharge patterns allowing the estimation of motor command structure. It is currently unclear how these various inputs are shaped to support greater contraction forces, or whether these motor commands undergo adaptation with chronic training or ageing. We aimed to characterise the relative contribution of neuromodulation and the pattern of inhibition to human MU discharge with increased contraction force in three experiments: 1) across three different muscles (tibialis anterior, TA; vastus lateralis and medialis) of healthy individuals (n=15); 2) in TA of resistance (RT; n=23), endurance (ET; n=16), and untrained (UT; n=23) individuals; and 3) in TA of older (n=14; 71±4 years) vs. younger (n=14; 24±5 years) adults.METHODS: In all experiments, participants performed isometric triangular contractions up to 30, 50, and 70% of maximal voluntary force (MVF) whilst high-density surface EMG signals were recorded, and decomposed into individual MU discharges that were then smoothed using support vector regression. Onset-offset hysteresis of pairs of MUs (ΔF) was calculated to estimate PIC magnitude. A quasi-geometric approach was used to garner insights into the neuromodulatory inputs (brace height) and the inhibition pattern (MU discharge acceleration, and post-acceleration [attenuation] slopes).RESULTS: Experiment 1. MU discharge patterns in all muscles were affected by contraction intensity, becoming more linear with lower slopes, but exhibiting greater discharge rate hysteresis. This suggests a reduced relative contribution of PICs to the increase in MU discharge and more reciprocal inhibitory patterns as a function of increased excitatory input.Experiment 2. RT exhibited greater discharge rates compared to ET and UT at 70% MVF. Both RT and ET exhibited more linear discharge patterns at 50 and 70% MVF compared to UT, though this appeared to be due to lower acceleration slopes in ET and lower attenuation slopes in RT. These results suggest modality-specific chronic training adaptations in the pattern of inhibition, with more reciprocal patterns associated with greater discharge rates and superior muscle force production in RT.Experiment 3. Older individuals exhibited reduced estimates of PICs at higher contraction intensities compared to sex-matched younger adults, suggesting modifications in the gain control of aged MUs.CONCLUSIONS: These experiments reveal that motor commands are uniquely shaped across contraction intensities, and that motor commands are modified with chronic training and ageing. The results also underscore the importance of contraction intensity when assessing the contribution of different components of motor commands to MU discharge.

S.9: From lab to living room - opportunities, challenges and potential using smart textiles and wearable solutions to facilitate self-administered home-based rehabilitation

S9.1: Co-creation of smart textile interventions for home-based rehabilitation after stroke – a case study

Leif Sandsjö, University of Borås; María Muñoz-Novoa, Gothenburg University; Peiman Khorramshahi, DaraLabs; Morten Kristoffersen, Center for Bionics and Pain Research; Margit Alt Murphy, University of Gothenburg; Li Guo, University of Borås

Background and Aim:About 80% of stroke survivors suffer from upper limb disorders. Shorter in-patient stays and limited access to rehabilitation programs puts a larger responsibility for functional recovery to the individual. In this context, technology-enabled, self-administered rehabilitation is presented as a way forward and biofeedback-based interventions using surface electromyography (sEMG) is a well-known candidate. However, current sEMG biofeedback methods are confined to the clinic, creating logistical hurdles which limit the training opportunities.This initiative aims to investigate the practicality, safety, and potential benefits of integrating smart textiles into post-stroke bio-feedback-based rehabilitation and explore if and how smart textiles solution(s) can improve the rehabilitation outcomes when performed by the patients themselves in their home environment. By introducing co-design of interventions, the study aims to harness insights from patients, healthcare professionals, and developers, ensuring user-centered and clinically relevant solution(s).Methods:The smart textile -based intervention(s) are formulated from a set of system components consisting of a) textile electrodes; b) sEMG acquisition system; c) biofeedback software app; d) data management and analysis platform. The co-design process focuses on optimizing these components for home-based self-administered interventions considering six distinct development aspects, i.e., i) targeted muscle(s); ii) textile electrode solution; iii) relevant training activities; iv) biofeedback measure(s); v) home-based training protocol; vi) user interface(s).The first stage of co-design involved technology developers working closely with healthcare professionals to understand the clinical and technical requirements and constraints related to home rehabilitation post-stroke to formulate a clinically viable prototype. At a second stage, the intervention will be further developed based on stroke survivors' input from testing the intervention at the clinic to

co-design a training protocol for home use.Results:Up to now (first stage) we have co-designed a system addressing (i) wrist flexors/extensors by means of (ii) a textile "sleeve" for the forearm comprising electrodes for wrist flexors and extensors to (iii) train wrist flexion/extension by (iv) providing feedback (bar graphs) when successfully activating or relaxing the targeted muscles. At the second stage it will be possible to test and provide users with individualized training protocols (v) based on their preferences, encompassing various types of exercises designed for use with the textile electrode system in the home environment. The resulting intervention(s) will then be investigated focusing on feasibility, safety, functional recovery, usability (vi), user compliance, and overall benefits.Conclusion:By actively involving stroke survivors, healthcare professionals, and system developers in the co-design process, we feel confident that the resulting solution(s) will be user-centered and clinically relevant. It is essential to emphasize that this is an evolving study, and further testing and development are underway to refine and enhance the capabilities and usefulness of the system. Our overarching objective is to provide stroke survivors with a convenient and efficient home-based rehabilitation tool that has the potential to contribute significantly to recovery and overall quality of life.

S9.2: Phantom limb pain treatment at home facilitated by a textile electrode system – a case study

Li Guo, University of Borås; Anna Brjörkquist, University of Borås; Leif Sandsjö, University of Borås; Morten Kristoffersen, Center for Bionics and Pain Research; María Muñoz-Novoa, Gothenburg University; Max Ortiz-Catalan, Bionics Institute

BACKGROUND AND AIM: Phantom limb pain (PLP) is a common and frequently distressing condition affecting amputees, posing significant challenges in pain management and quality of life. Traditional approaches to managing PLP, such as mirror therapy, are not always effective, arguably because they can become tedious, leading to reduced patient engagement. Advanced treatments like biofeedback and VR/AR based interventions typically require continuous assistance from healthcare professionals, making independent, at-home management challenging due to the complex setup involved. This study aims to investigate the efficacy and user satisfaction of a novel textile-based solution, designed for PLP management, tested in home environments. The research focuses on evaluating the personalized textile electrode systems for rehabilitation techniques and deepening insights into the nuances of at-home PLP management.METHODS: A qualitative study involving six participants with PLP was conducted. Each participant used a textile-based electrode system to perform phantom motor execution treatment over 3 to 6 months in their home environment. The study comprised two intervention phases: the initial phase, guided by the research team, aimed to validate the effectiveness of the textile electrode system. The second phase allowed participants independence in using the system, focusing on user compliance and satisfaction in a home setting. Qualitative data were gathered through semi-structured interviews following each intervention period, aiming to comprehensively document variations in type and level of pain, user experiences, and practical challenges encountered. The primary analysis of this data was conducted by the authors using Nvivo. Additionally, OpenAI's ChatGPTwas employed as a supporting tool, offering supplementary insights into the qualitative analysis.RESULTS: Participants reported varying degrees of pain relief, with some experiencing significant reductions in PLP intensity. Main themes included improved pain management, positive impacts on daily activities, and overall life quality improvement. Challenges in system usability, particularly concerning cable management and difficulties with games, were highlighted; however, the textile prototype received positive feedback for its ease of use, reliability, and customizable treatment options. Additionally, the need for improvement to make the treatment more entertaining and challenging was identified, emphasizing their potential role in boosting user motivation and compliance with the treatment regimen.CONCLUSIONS: The study highlights the importance of personalized rehabilitation, showcasing textile-based solutions as effective in managing PLP. The findings point towards a shift in rehabilitation practices, leaning more towards user-centered methods. AI's role in data analysis provided supplementary insights, enriching our understanding of participant experiences. Ultimately, the findings of this research open new possibilities for applying textile-based solutions in broader rehabilitation contexts, promoting their adoption in routine healthcare practices.

S9.3: Integrating textile electrodes into pants for transcutaneous electrical nerve stimulation in postoperative pain relief

Yohann Opolka, University of Borås; Courage Sundberg, Karolinska University Hospital; Robin Juthberg, Karolinska Institute, Department of Molecular Medicine and Surgery, Solna, 171 76 Stockholm; Amelie Olesen, University of Borås; Li Guo, University of Borås; Paul W. Ackermann, Karolinska University Hospital, Solna, 171 76 Stockholm; Nils-Krister Persson, University of Borås

BACKGROUND AND AIM: Patients undergoing hip surgery often face severe postoperative pain, which can significantly affect their recovery and quality of life. Traditional pain management methods, including medication, have their drawbacks. This study explores the use of Transcutaneous Electrical Nerve Stimulation (TENS) integrated into specially designed pants, aiming to provide an easy-to-use and effective pain relief option that also enhances mobility and comfort post-surgery. This approach also aims to address the need for more patient-centered and self-administered pain management strategies in post-surgical care.METHODS: The study involved the design and development of a wearable solution - TENS pants. Special attention was given to the garment construction, ensuring flexible placement of TENS electrodes and overall ease of use for the pants. The iterative design process involved feedback from caregivers and users to maximize comfort, usability, and effectiveness in pain relief. A pilot study, a randomized single-blinded placebo-controlled trial (RCT) was conducted with thirty post hip surgery patients, to study the feasibility of using the TENS pants at a hospital.RESULTS: Results from the RCT study demonstrated a significant improvement in pain management compared to a placebo group in reducing postoperative pain and enhancing patient mobility. In addition, feedback from patients and healthcare professionals during the study resulted in the development of prototype pants for home use. This prototype, a tangible outcome of the study, addresses key aspects of usability and wearability and makes fully self-administrable pain relief possible in the home environment.CONCLUSIONS: The integration of TENS into textiles, as demonstrated by the TENS pants, has shown a promising direction in postoperative pain management for hip surgery patients. These pants have not only significantly reduced pain and improved mobility but also introduced an innovative and easy-to-use solution for self-administered pain management for home use. Future research will explore the long-term use and effectiveness of this home-use prototype, aiming to provide further insights into enhancing patient recovery and independence after surgery.

S9.4: Easy-to-use sEMG wearable device to monitor muscle activity at the clinic or at home

Elisa Romero Avila, Institute of Applied Medical Engineering; Catherine Disselhorst-Klug, Institute for Applied Medical Engineering, RWTH Aachen University

BACKGROUND AND AIM: The field of rehabilitation has observed, over the past years, an increase in the use of wearable devices for monitoring and assessing a person's movement performance. One of the methods used for this includes the recording of surface electromyography (sEMG). These wearables provide insights into a patient's condition and allow them to adjust their therapy, even at home. However, the quality and suitability of the recording may differ among the different devices. Accordingly, a 16-channel sEMG sensor system has been developed to be used autonomously and intuitively by patients with reduced arm function and without detailed knowledge about the exact positioning of the sEMG electrodes. This work aims to demonstrate the device's potential, including its feasibility and accuracy in identifying relevant sEMG channels, particularly in comparison to commercial sEMG systems that use pre-gelled electrodes. METHODOLOGY: The design includes a multichannel approach consisting of dry electrodes arranged in a circular form around the limb. The device is size-adaptive, and the 16 sEMG channels are distributed in eight modules, thus providing two sEMG channels per module to ensure correct localization and recording of muscles of interest. As a result, it increases the possibility that at least one sEMG channel is correctly positioned, and inexperienced users have more flexibility in electrode placement. Moreover, the sensor system ensures stable contact between the electrodes and the skin while compiling with the sEMG standards regarding electrode size and inter-electrode distance. The proof-of-principle of the device was proved during elbow flexion/extension movements by ten subjects. An algorithm was developed to identify the relevant channel recording the muscular activation of the biceps since it is one of the primary muscles involved in elbow flexion/extension movements. Then, the sEMG sensor system was repositioned before each trial, and the results were compared to those obtained using a conventional sEMG system with pre-gelled electrodes. RESULTS: The results indicate that even when placed by inexperienced users, the system adequately tracks muscular activation with sufficient accuracy and a signal quality comparable to conventional sEMG systems. The algorithm on the sEMG sensor system identified the relevant sEMG channel in more than 90% of the trials. Furthermore, the device was easily placed and removed by the subjects. CONCLUSION: These features enable the sEMG sensor system to be a promising instrument for tracking muscular activation and guiding the rehabilitation of patients with movement disorders in the clinic or at home. Besides enabling the monitoring by the medical staff and providing direct feedback to the patient, it may also be considered for future applications related to the control of smart prosthetics and orthotics.

S9.5: Gel-free textile-based electrodes for enhanced surface electromyography: towards efficient home-based health applications

Xi Wang, University of Borås; Yuqi Wang, The University of Manchester; Li Guo, University of Borås; Xuqing Liu, Northwestern Polytechnical University; Leif Sandsjö, University of Borås

Background and Aim:The development of easy-to-use surface electromyography (sEMG) in home-based health practices is increasingly recognized. Textile-based electrodes offer a promising approach for self-administered health monitoring due to their easy integration into everyday life, reducing barriers to practical use. However, textile-based electrodes, particularly

in sEMG applications, still face challenges related to electrode-to-skin impedance, reliance on conductive gels, and, most importantly, the need to record from a well-defined position that prevents the electrode(s) from moving over the skin. This study aims to overcome these limitations of textile-based electrodes, particularly in enhancing electrode contact and adhesion to the skin.Methods:The study employs Carbon Black (CB) encapsulated in one type of biocompatible elastomer, i.e. Ecoflex. Encased in an interphase layer, CB forms colloidal dispersions, facilitating quantum tunneling and percolation, with the quantum interfacial effect influenced by the distance between CB and the polymer inherent potential barrier, to maintain stable conductivity during movement. Additionally, a proportion investigation is applied to exhibit enhanced surface energy, due to silicon hydroxyl bonds, creating a skin-adhesive interface to improve skin-electrode contact and maintain a defined position over the muscle. The feasibility of the CB/Ecoflex electrodes was tested by comparing the myoelectric activity (sEMG) in relation to the signal recorded by standard Ag/AgCl electrodes.Results:The developed electrodes exhibit good flexibility, stable electromechanical properties, and lower skin contact impedance. These electrodes, which do not require conductive gel, show a signal quality comparable to the standard Ag/AgCl electrodes during sEMG tests. Their efficacy was demonstrated by sEMG recordings from the wrist flexors and extensors while performing a series of hand/wrist activities.Conclusion:The gel-free, durable, and skin-conformable textile electrodes developed in this study show great potential in facilitating easier usage in home-based monitoring, treatment, and rehabilitation. They represent a more accessible and effective step forward in integrating soft electronics with biomedical engineering, promising the development of advanced, comfortable, and non-invasive health monitoring technologies in medical diagnostics, sports science, and rehabilitation applications.

S.10: Factors influencing neuromodulation of motoneurons and/or PICs: What do human studies tell us and what are the applications?

S10.1: Pharmacological manipulations of the serotonergic system reveal neuromodulatory effects at human motoneurons, but what do different tests of motoneuron excitability tell us?

Jacob Thorstensen, The University of Queensland; Tyler Henderson, Griffith University; Benjamin Goodlich, Griffith University; Justin Kavanagh, Griffith University

Descending motor pathways recruit spinal motoneurons to activate muscle fibres, whereby ionotropic and neuromodulatory inputs work in harmony to control the firing characteristics of pools of motor units. Ionotropic inputs such as the corticospinal system quickly bring motoneurons above their threshold for discharge. In contrast, motoneuron excitability is drastically altered by slower-acting metabotropic neuromodulators such as serotonin (5-HT) released from the brainstem raphe nuclei. Decades of animal work indicate that 5-HT has net faciliatory effects on motoneuron excitability, whereby more muscle force can be produced for the same excitatory input to motoneurons when 5-HT is released in the spinal cord. To enhance motoneuron excitability, amongst other mechanisms, 5-HT appears to strongly enhance the amplitude of voltage-gated persistent inward currents (PICs), which amplify and prolong excitatory synaptic input.In recent years, there has been an extended effort to translate the observed effects of 5-HT on motoneuron excitability in animals to humans. Specifically, several double-blinded, placebo-controlled drug studies involving drug interventions that either enhance 5-HT availability or antagonise its activity at the excitatory 5-HT2 receptor, have been paired with gold-standard tests of motoneuron excitability to provide insight into the neurochemical effects of 5-HT at motoneurons in humans. Several different tests have been used to assess 5-HT drug effects at motoneurons, including transcranial magnetic stimulation (TMS) of the motor cortex to evoke electromyogram recorded motor evoked potentials (MEPs), cervicomedullary stimulation to evoke cervicomedullary motor evoked potentials (CMEPs), peripheral nerve stimulation to evoke F-waves, and high-density surface electromyography (HDsEMG) derived estimates of PICs. However, not all these tests detect changes in motoneuron excitability after 5-HT drug administration, and this could be due to subtle differences in the ways in which they assess motoneuron excitability. Likewise, 5-HT drug effects on measures of motoneuron excitability appear to be contraction-intensity dependent, whereby drug effects are more prevalent when more inputs to motoneurons are active.This presentation will discuss the effects of 5-HT drugs across several different measures of motoneuron excitability in humans, and what this tells us about the serotonergic control of motoneuron activity (with a particular focus on PICs). Specifically, we will compare 5-HT drug effects identified with HDsEMG estimates of PICs, to drug effects observed with neurostimulation of the motor system, and how outcomes associated with these techniques are affected by the magnitude of voluntary contraction that likely changes the magnitude of serotonergic drive to motoneurons.

S10.2: PICture this – an expansive analysis repertoire for unravelling the effects of persistent inward currents on the control of human motor output

Greg Pearcey, Memorial University of Newfoundland; James Beauchamp, Carnegie Mellon University; Jakob Škarabot, Loughborough Universit

BACKGROUND AND AIMHuman movement is achieved via activation of spinal motoneurons and their innervated muscle fibers, collectively known as motor units. Motoneuron discharge times are accessible in humans due to the one-to-one relationship between action potential discharges of the motoneuron and its innervated muscle fibers. Human motor unit recordings therefore provide valuable information about motor commands and biophysical properties of human motoneurons.It was once believed that motoneurons were passive integrators of net synaptic inputs, however, it is now clear that they possess active properties that can transform synaptic inputs to a great degree. During slowly increasing inputs, motoneuron discharge rates rapidly accelerate (secondary range), which reflects the onset activation of intrinsic persistent inward currents (PICs) in motoneurons. PICs further shape the discharge behaviour of motoneurons by producing sustained plateau potentials, which cause motoneuron discharge rates to increase linearly in response to an increasing intracellular current injection but with a much shallower slope. This lower-gain response, termed tertiary or rate attenuation range, reflects an increase in membrane conductance produced by the sustained opening of the Na and Ca channels mediating PICs. The tertiary range also exhibits a pronounced hysteresis whereby the sustained plateau potential mediated by PICs allows the motoneuron to discharge at inputs well below that needed to initially recruit the motoneuron. This hysteresis in discharge rate reflects the PICs contribution to self-sustained firing of the motoneuron and can be measured by the reduction in current injected into the soma at the offset of motoneuron discharge (de-recruitment) compared to the higher current required to initiate firing at recruitment.The number of studies estimating the effects of PICs on human motor unit discharge profiles has exploded in the last decade or so, but the analysis has primarily focused on hysteresis only. This has been achieved via the well-established paired motor unit analysis technique. Further quantification of PIC-induced features of motor unit discharge rate profiles therefore provides great potential to understand human motor commands and biophysical properties of human motoneurons.METHODSSeveral emerging methods, that move beyond the well-established paired motor unit analysis technique (DF), will be discussed to facilitate further understanding of mechanisms contributing to changes in motor unit discharge behaviour. In particular, the assessment of non-linearities of motor unit discharge rate with respect to linear changes in behaviour (e.g., force or torque) will be used to provide insights about changes in motor commands that can contribute to changes in DF.RESULTSSeveral experimental datasets will be discussed with regards to the amplitude, duration, and slope of the discharge rate acceleration (secondary firing range) and attenuation (tertiary firing range). In combination with realistic motoneuron models, these results allow unprecedented insights about changes in the patterns of neuromodulation and inhibition received by motoneuron pools during human behaviour.CONCLUSIONSEmerging methods for the analysis of human motor unit discharge profiles discussed in this presentation will facilitate a greater understanding of human motoneuron function in both heath and disease.

S10.3: Effect of experimental joint pain on estimates of persistent inward currents

Francois Hug, Université Côte d'Azur; Jacob Thorstensen, The University of Queensland; Manuela Besomi, The University of Queensland; Wolbert Van Den Hoorn, School of Biomedical Sciences, The University of Queensland, Australia; Kylie Tucker, The University of Queensland

BACKGROUND AND AIM. There is a series of studies reporting an overall decrease in motor neuron discharge rate during contractions with matched force when pain is induced experimentally in muscle or non-muscular tissue. Recent data show evidence of differential modulation of the activity across the motor neuron pool, with an increased discharge rate of some motor neurons. Possible mechanisms for these changes in motor neuron discharge characteristics involve persistent inward currents (PICs), which are activated by voltage-dependent ion channels and lead to a non-linear relationship between the net synaptic input received by a motor neuron and its output. The aim of this study was to assess the effect of experimental pain on the estimates of PICs and motor unit discharge characteristics. METHODS.10 participants (8 males, 2 females) performed triangular and trapezoid isometric knee extensions to a peak of 30% of their maximum voluntary contraction. Three conditions were tested: one control condition that preceded a condition where pain was induced in the knee fat pad by injection of hypertonic saline, and a washout condition performed after pain had completely ceased. We recorded high-density surface electromyography (HDsEMG) signals from the vastus lateralis (256 electrodes), and vastus medialis (128 electrodes) muscles. Signals were decomposed with convolutive blind source separation to identify motor units spike trains. A paired-motor-unit analysis was used to calculate ΔF, which is assumed to be proportional to PIC magnitude. RESULTS: Data are reported only for the Vastus lateralis muscle. An average of 26.6±15.1 (range: 8-58) motor units per participant were identified. When considering the trapezoid contractions, there was a significant decrease in motor unit discharge

rate during pain (main effect; p<0.05 for both matched and unmatched motor units). However, the ΔF was not significantly affected by experimental pain (main effect p>0.05 for both matched and unmatched motor units). As we identified a relatively large number of motor units, we were able to run statistics for each participant separately. We observed large interindividual variability, with 5 participants exhibiting a significant decrease in ΔF during pain, 4 participants showing an increase and 1 participant showing no change. CONCLUSION. The effect of experimental pain onPICs appears to be individual-specific. Further work is needed to assess the robustness of these adaptations and to understand the reasons for this interindividual variability.

S10.4: Altered motor neurone firing patterns unravel impaired neuromodulatory and inhibitory effects on persistent inward currents in older adults

Lucas Orssatto, Deakin University

Muscle force production requires appropriate levels of synaptic input to the motor neurones, the final common pathway to muscle. Subsequently, the motor neurones are responsible for integrating and modulating excitatory synaptic input to evoke an appropriate motor unit firing output. Motor neurones can generate persistent inward currents (PICs), which are depolarising currents produced by specialised voltage-sensitive sodium and calcium channels within their dendrites. PICs increase cell excitability, accelerating, amplifying, and prolonging motor neurone output activity for a given synaptic input.Deteriorations observed within the function of aged motor neurones cause them to fire at lower frequencies, thereby reducing the ability of older motor units to produce high levels of force. Recent studies suggest that the lower firing frequencies observed in the older population could be partially explained by impairments in the ability of aged motor neurones to generate PICs. Studies tested various muscle groups, such as tibialis anterior, soleus, vastus lateralis, and biceps and triceps brachii. However, they relied solely on estimates of PIC contribution to motor neurone firing obtained from the paired-motor unit analysis method (to calculate Δ Frequency - ΔF). Although this method is considered the best current estimate of PICs in physiologically activated motor neurones, novel robust metrics have demonstrated the potential to provide a broader understanding of PICs when combined with ΔF data. A quasi-geometric approach has been developed and demonstrated validity in quantifying the neuromodulatory effects of PICs and inhibitory effects on PICs, influencing individual motor unit firing patterns. However, these metrics have not been explored in the aging context to date. This presentation will highlight:i) Recent work demonstrating that estimates of PIC contribution to motor neurone firing (estimated with paired-motor unit analysis to calculate ΔF) are reduced in older individuals;ii) Our novel data showing age-related changes to neuromodulatory and inhibitory input influencing PIC effects on motor neurone firing patterns. These were estimated with novel quasi-geometric metrics, such as brace height, acceleration and attenuation slopes, and angle.iii) Current evidence of PIC facilitation and inhibition impairments that could be contributing to reductions in general functional capacity in older adults.Collectively, data obtained from these metrics improve our understanding of age-related impairments in PIC contribution to reduced motor neurone firing, force production, and physical function in older adults. A better understanding of this motor neuronal mechanism can lead to the development of more effective strategies—whether through exercise, nutrition, and/or pharmacological interventions—to alleviate the debilitating effects of aging and improve the physical function and general quality of life of older adults.

S.11: Neurorehabilitation pipeline for upper extremity motor paralysis after stroke: xR, non-invasive brain stimulation, and Constraint-induced movement therapy

S11.1: Rehabilitation treatment package for optimal option adaptation to the stroke survivor's individual motor function

Fuminari Kaneko, Tokyo Metropolitan University

For post-stroke upper extremity (UE) motor paralysis, a multistep treatment strategy according to the functional status of individuals is significantly important. According to Liu et al. (2012), for individuals with UE paralysis after stroke, if electromyography (EMG) of finger extensors is not detectable, motor imagery-based training is an option (Level 1). If EMG of finger extensor muscles is detectable, functional electrical stimulation therapy is feasible (Level 2). Constraint-induced movement therapy may be selected as appropriate option if the patient is at a level where actual joint motion occurs, not just EMG (Level 3). As a treatment of motor imagery-based training, passively induced kinesthetic illusion with visual stimulation (Passive-KNVIS) is one option for people with Level 1 function.The seamless treatment strategy of applying the appropriate treatment option is called a "neurorehabilitation pipeline." In this presentation, I will propose a novel multistep treatment package as a neurorehabilitation pipeline. Kawakami et al. (2016) demonstrated that motor function improved when HANDS therapy, which is also included in our treatment package, was applied to individuals with improved finger extensor muscle activity following motor imagery-based training. However, there seemed to be a large gap in functional status between Levels 1 and 2. After finger extensor EMG activity was detectable during the hand movement, HANDS therapy could be performed even when extensor and flexor muscles were co-contracted. Therefore, we recently developed a novel EMG-feedback therapy (active-augmented body movement control with neuromuscular feedback system therapy [Active-AUMOC]) for individuals in whom the finger extensor muscle activity was detected after Passive-KINVIS, but co-contraction of the extensor and flexor muscles was observed (Level 1.5).In short, we propose to offer a novel multistep treatment package for individuals with severe motor paralysis after stroke in the chronic phase: Passive-KINVIS, Active-AUMOC, and HANDS therapy.To choose the appropriate approach for individuals, we used clinical assessments measuring motor function and EMG tests to determine whether to proceed to the next therapies in the treatment package or which therapies to apply for individuals with stroke.Let me first talk about Passive-KNVIS, which we developed. With KINVIS therapy, individuals with stroke can feel as if their paralyzed real body has been replaced by an artificial body with enhanced motor functions. Based on the results of our experimental studies and clinical trials, we will present the physiological and cognitive effects of Passive-KINVIS. The next step will be the results of application of our novel multistep treatment option package to individuals with severe motor paralysis after stroke in the chronic phase.

S11.2: Robotic rehabilitation for upper limb motor disorders after stroke

Takashi Takebayashi, Osaka Prefecture University

Stroke is the third leading cause of death worldwide, and it leaves residual effects, diminishing the quality of life (QOL) in later years. Many stroke survivors experience residual upper and lower limb motor deficits that manifest after the onset of stroke. Motor impairments in the upper limbs affect activities of daily living and are reported to significantly reduce patients' quality of life.Recently, robotic therapy has been reported as effective in treating upper limb motor impairments that arise after a stroke in guidelines from around the world. Robotic therapy is also noted for promoting functional recovery by ensuring an appropriate level of activity in the affected upper extremity when used as independent practice outside of therapist-provided rehabilitation time (Winstein et al., 2016).In our previous randomized controlled trial (RCT) investigating the effectiveness of robotic therapy as an adjuvant therapy using ReoGo-J (Teijin Pharma Limited, Tokyo, Japan), we observed no significant improvement in affected upper extremity function with robotic therapy used as a voluntary exercise compared to the group performing conventional voluntary exercise. However, there was no significant difference in the behavior (frequency of use) of the paralyzed hand in real life (Takahashi et al., 2016). Therefore, to transfer the functional improvement developed by robotic therapy to activities of daily living, we conducted a study using Constraint-Induced Movement Therapy (CIMT), recommended by international guidelines for improving the affected upper extremity use in daily life (Takebayashi et al., 2018).Based on the above hypothesis, an RCT was conducted to test the effects of robotic therapy and CIMT. The results suggested that the group receiving both robotic therapy and CIMT as independent practices significantly improved the behavior of paralytic hand use in daily life compared to the group receiving both conventional independent practice and conventional rehabilitation (Takebayashi et al., 2022). These results emphasize the importance of understanding the characteristics of robotic therapy and human-provided CIMT and integrating them into rehabilitation for the paralyzed hand after a stroke.Finally, we are currently developing an algorithm that will enable ReoGo to automatically recommend tasks of appropriate difficulty based on the severity of the patient's upper extremity motor impairment. The results have shown that, once the function of the paralyzed hand is assessed in the shoulder, elbow, and forearm categories of the Fugl-Meyer Assessment, it is possible to recommend appropriate exercises according to the patient's upper extremity function (Takebayashi, et al. 2023). This algorithm will be briefly discussed at the end of this lecture.

S11.3: Applications of transcranial magnetic stimulation in rehabilitation medicine

Michiyuki Kawakami, Keio University School of Medicine

Repetitive transcranial magnetic stimulation (rTMS) has long been used in clinical practice. rTMS is a method of changing the excitability of the cerebral cortex by varying the stimulus intensity, frequency, and frequency of repetitive stimulation. Recently, patterned form of rTMS has become more common as a more powerful stimulation method, and its representative stimulation methods are quadripulse stimulation (QPS) and theta burst stimulation (TBS). Both QPS and TBS have similarities in that they can induce LTP (Long-Term Potentiation)/LTD (Long-Term Depression)-like changes more powerfully than regular rTMS, and both have stimulation methods that produce a stimulatory effect and a suppressive effect. For example, when used to treat stroke patients, QPS and TBS are used to increase the excitability of the primary motor cortex of the injured side of the brain or to reduce the excess inhibition (interhemispheric inhibition) of the injured side of the brain by decreasing the brain activity of the non-injured side. TBS is easy to use in clinical situations because of its short stimulation time (90 to 190 seconds), and the number of research papers on TBS has increased. Several systematic reviews and meta-analysis studies have reported the efficacy of TBS in improving motor cortical plasticity, motor function, and daily functioning in stroke patients. Although the 30-minute stimulation time required for QPS is a hurdle to its clinical application, the relatively low inter-subject variability of its effects makes it easy to predict the effects that will be obtained.These magnetic stimulation techniques are expected to be used in combination with neurorehabilitation techniques. This presentation will focus on magnetic stimulation as a treatment for central motor paralysis in particular, and in combination with other rehabilitation techniques.

S.12: Back in action: muscles, mechanics, and movement in adolescent idiopathic scoliosis

S12.1: Quantifying full spine paraspinal muscle volume, intramuscular fat and fat-free muscle asymmetry in adolescent idiopathic scoliosis

Phoebe Duncombe, The University of Queensland; Taylor Dick, University of Queensland; Phoebe Ng, KK Women's and Children's Hospital/ The University of Queensland; Maree Izatt, Biomechanics and Spine Research Group, Centre for Children’s Health Research, Australia; Robert Labrom, Biomechanics and Spine Research Group, Centre for Children’s Health Research, Australia; Kylie Tucker, The University of Queensland

Adolescent idiopathic scoliosis (AIS) is characterized by an atypical 3D spinal curvature that develops/progresses between ages 10-18 years. Asymmetry in paraspinal muscle size and quality influences force-generation capacity and may contribute to asymmetrical vertebral growth. We aimed to quantify paraspinal muscle volume and intramuscular fat asymmetry in female adolescents with AIS and age-matched controls.Methods: T1-weighted and mDixon MRI scans were performed on 23 female adolescents with primary-right-convex thoracic scoliosis [Cobb angle: 38±16°; age: 13.7±1.5 years]; and 20 controls [age: 13.6±1.9 years]. Muscle volumes (multifidus and longissimus) were determined at vertebral levels T6 to L4. Fat-fraction maps from mDixon scans were co-registered with muscle volumes to determine intramuscular fat proportions. Muscle, intramuscular fat, and fat-free volume asymmetry indices [ln(concave/convex)] were determined.Results: This work identified significant asymmetries in the AIS participants' paraspinal muscle volume, intramuscular fat and fat-free muscle along the full length of the scoliotic curve, which were greater than observed in control participants with symmetrical spines (p<0.05).Multifidus's volume was significantly greater on the concave-side of the spine near the thoracic scoliotic curve apex and greater on the convex-side in the lumbar spine for the AIS group (p<0.05, Fig 1A). For longissimus, only the volume at the 3rd vertebral level above the apex was greater on the concave side (p<0.05, Fig 2A).Both multifidus and longissimus intramuscular fat were significantly greater on the concave-side of the spine near the thoracic scoliotic curve apex (p<0.05, Fig 1B and 2B) and in the lumbar spine, greater on the convex-side for the AIS participants (p<0.05, Fig 1B and 2B).Multifidus fat-free muscle volume three vertebral levels above the apex was significantly greater on the concave-side and greater on the convex-side at the 5th vertebral level below the apex (p<0.05, Fig 1C). For longissimus, only at the 3rd vertebral level above the apex was the fat-free muscle volume greater on the convex-side (p<0.05, Fig 2C).Discussion: Compared to the control group, participants with AIS have significant asymmetry in multifidus volume, intramuscular fat, and fat-free muscle across multiple vertebral levels around the thoracic curve apex and in the lumbar spine. Longissimus also has significant asymmetry in intramuscular fat levels around the apex of the thoracic curve and the lumbar spine. This provides evidence of an imbalance in the force-producing capacity of paraspinal muscles in AIS, particularly in the deep paraspinal muscle, which applies forces to the transverse and spinous processes of the vertebrae. The next step in this data collection is to determine if these asymmetries are correlated with curve severity, future progression of the curve, and bony asymmetries identified in our participants with AIS.

S12.2: Maximal and asymmetrical submaximal paraspinal muscle activation in Adolescent Idiopathic Scoliosis during simple back extension tasks

Phoebe Duncombe, The University of Queensland; Andrew Claus, Royal Brisbane and Women's Hospital, Australia; Maree Izatt, Biomechanics and Spine Research Group, Centre for Children's Health Research, Australia; Peter Pivonka, Queensland University of Technology; Robert Labrom, Biomechanics and Spine Research Group, Centre for Children's Health Research, Australia; Wolbert Van Den Hoorn, School of Biomedical Sciences, The University of Queensland, Australia; Kylie Tucker, The University of Queensland

BACKGROUND AND AIMCurve progression in adolescent idiopathic scoliosis (AIS) is associated with three-dimensional wedging of spinal vertebrae and discs [1]. It is well known that muscle activity and morphology influence muscle force generation, and that the forces applied to bones and discs are substantial moderators of growth and adaptation [2]. There is growing evidence for asymmetrical force-generating capacity in paraspinal muscles in AIS [3,4]. However, data varies greatly between studies, and previous outcomes are highly dependent on the methodological approaches taken [5].The aim of this study was to determine if the symmetry of paraspinal muscle activation amplitude differs in adolescents with AIS compared to controls, during a voluntarily driven, symmetrical, submaximal task.METHODSFemales with AIS (primary right thoracic curves, n=24, mean[SD] age: 13.8[1.5] years) and without AIS (n=20, 13.8[1.8] years) were recruited through a Spine outpatient clinic at the Queensland Children's Hospital and the local community.Six maximal trunk extensions were performed in lying: three in an unresistedpose, and three were manually resisted at the shoulders and thighs. The maximum activation recorded in any trial, for each muscle separately, was used for normalisation. Participants then performed a series of five (20-30s) submaximal trunkcontractions (Fig 1A), which was between 10-20% of their maximal activation (i.e. 10-20% MVC, from T9 left + right). Muscle activity was recorded using bipolar surface electrodes placed bilaterally atvertebral levels: T9 and T12 (Fig 1B, note that data from C7 and L5 were also recorded as part of a larger study but not reported as part of this study).The symmetry index of muscle activity was determined usingLn(right/left), which equates to Ln(convex/concave) in the AIS cohort. To assess the difference in muscle activation symmetry index between the groups, repetitions (1-5) and vertebral levels, a linear mixed model analysis was conducted. Participants were entered as random intercepts, with repetition, and interaction between group and vertebral level included as a fixed effects.RESULTSGreater paraspinal muscle activation asymmetry (convex>concave) was observed at the apex of those with AIS versus T9 of the control group (Estimate 0.36, 95%CI 0.05 to 0.80, p=0.002). There was no difference in activation symmetry between groups at T12 (Estimate 0.27, 95%CI -0.04 to 0.58, p=0.12).CONCLUSIONSCompared to control participants, adolescents with AIS display greater asymmetry in paraspinal muscle activation at T9 during submaximal trunk extensions. This asymmetry was not observed at T12. Asymmetric paraspinal muscle activation may contribute to asymmetrical muscular forces for spines developing in children with AIS.REFERENCES[1] Negrini et al. Scoliosis Spinal Disord 13: 1-48, 2018[2] LeVeau et al. Phys Ther, 64: 1874-82, 1984.[3]Kennelly K and Stokes M. Spine 18:913-7,1993[4] Meier MP et al. Spine 22: 2357-64, 1997.[5] Ng et al. J Electromyogr Kinesiol63: 1-11, 2022.

S12.3: Towards understanding paraspinal muscle activation asymmetry in idiopathic scoliosis – A pilot study

Juha-Pekka Kulmala, Helsinki University Hospital; Mikko Mattila, Helsinki University Hospital; Andrey Zhdanov2, Helsinki University Hospital; Jari Arokoski, Helsinki University Hospital

Background and Aims:Etiology of adolescent idiopathic scoliosis (AIS) is still unknown. Because adolescent spine is flexible, asymmetry in the paraspinal muscle activation may potentially play a role in the development of scoliosis. While some electromyographic (EMG) studies have reported higher activation in the convex side others have found no differences (1). Mixed findings may be due to fact that previous studies have analysed absolute rather than normalised EMG results, although latter is commonly recommended (1).Several normalisation procedures have been described, such as the reference to a maximal voluntary contraction (MVC) or sub-maximal (SubMax) voluntary contraction. We aimed to compare whether these methods provide a comparable results for muscle activation asymmetry in AIS.Methods:Paraspinal muscle activations at lumbar (L4 & L2) level and thoracic level (T11) were recorded during MVC and SubMax task. For aMVC, we used back extension task, and as a sub-maximal task, we used backward walking on a treadmill while pulling the ropes (Figure 1).EMG data were filtered with a bandpass filter (20-500Hz), and then rectified and low pass filtered using a 4th order Butterworth low-pass filter (10 Hz). We report absolute EMG values and asymmetry indexes of both methods from four AIS patients. We also report normalised EMG results during walking when using MVC and SubMax normalisation procedures.Results:The absolute paraspinal muscle activations were about two times greater in MVC versus SubMax method (Fig 2). The mean asymmetry index showed relatively similar values between MVC versus SubMax method. However, at the individual level, notable differences between the two methods were observed especially at the T11 level: For the two participants (2 & 3), SubMax method provided greater activation on the right side whereas MVC method showed greater activation in the left side (Fig. 2). This results in a clearly greater side-to-side asymmetry in these participants during walking when analysed using MVC versus SubMax method (Fig 3).Discussion:We observed contracting results for between side paraspinal muscle activation level in some of the patients in the MVC versus SubMax measurements. It remains unclearto what extent these differences depends onpatients' altered activation strategy in SubMax task, and on the other hand, the patients' ability to achieve maximum voluntary activation in the MVC task. To better understand paraspinal muscle function in AIS, wecall for further research examining muscle activation strategies across different tasks and effort levels.ReferencesNg, P.T.T., Claus, A., Izatt, M.T., Pivonka, P. and Tucker, K. (2022).Is spinal neuromuscular function asymmetrical in adolescents with idiopathic scoliosis compared to those without scoliosis?: A narrative review of surface EMG studies. Journal of Electromyography and Kinesiology, 63 102640, 102640. doi: 10.1016/j.jelekin.2022.102640

S12.4: Novel technology and methods for the assessment of deformity and function in Adolescent Idiopathic Scoliosis

Jessica Wenghofer, University of Ottawa; Kristen Beange, Carleton University; Wantuir, Carlos, Jr. Ramos, University of Ottawa; Mina Maksimovic, University of Ottawa; Matthew Mavor, University of Ottawa; Kevin Smit, The Children's Hospital of Eastern Ontario; Ryan Graham, University of Ottawa

Background and Aim: Adolescent Idiopathic Scoliosis (AIS) is a complex deformity that often requires early intervention to prevent the progression of the spinal curvature and, in many cases, a potential loss of function. This research highlights novel technologies for assessing AIS and spine function by presenting three studies: Study 1) the use of smartphones and deep learning (DL) to screen for AIS; Study 2) validation of an inertial measurement unit (IMU) based methodology to clinically assess spine motion in patients with AIS; and Study 3) development of a spine motion capture system using DL and a red-green-blue-depth (RGB-D) camera. Methods: In Study 1, 68 participants (53 AIS, 15 control) were recruited from the Children’s Hospital of Eastern Ontario and were imaged with a smartphone containing a depth sensor. Participants were randomly divided into train and test datasets with an 80:20 split. The training dataset was used to train a DL algorithm to classify participants based on diagnosis (AIS or control). The test dataset was used to assess model performance by measuring the model’s accuracy, sensitivity, and specificity. In Study 2, spine kinematics of 10 participants performing dynamic trunk movements were simultaneously collected by optical (OPT) and IMU systems (equipment placed at C7, T12 and S1 vertebral levels) to assess concurrent validity and reliability of the IMU system to track absolute (C7, T12, and S1) and relative (thoracic, lumbar, and total) spine movement and range of motion (ROM). In Study 3, 15 participants performed repetitive flexion-extension while recorded with an RGB-D camera. ROM was controlled by adjusting targets in the sagittal midline to shoulder and knee height. Participants were divided into train and test datasets with an 80:20 split. These data were used to train a DL algorithm to segment the posterior trunk into upper spine, lower spine, and pelvis segments. The corners of these segments were then used to create a 3D global coordinate system, enabling the measurement of spine kinematics and comparison to a gold-standard OPT system. The root means square error (RMSE) and intraclass correlation coefficients (ICC) were measured between the RGB-D and OPT systems.Results: Study 1: An accuracy of 96% was achieved with a sensitivity and specificity of 99% and 82%, respectively. Study 2: The IMU method calculated kinematics within 2° RMSE of the OPT system and had excellent reliability for estimating ROM (ICC2,1 ≥ 0.950). Study 3: The algorithm achieved RMSE values <5° compared to the OPT system and was able to measure both lumbar and total spine kinematics.Conclusions: The results from these studies demonstrate that portable and inexpensive technology can be used to screen for AIS and measure spinal function through dynamic movements, making participation in research studies more accessible and demonstrating the potential for at home assessments and large-scale, multi-centre research studies.