6th International Autumn School on Movement Science

Berlin, 7th to 11th October 2019

Programme

BSMS
Berlin School of
Movement Science

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DAAD

Hosted by

Humboldt-Universität zu Berlin, Institute of Sports Science

BSMS – Berlin School of Movement Science

Organisation

Scientific Coordination
Prof. Adamantios Arampatzis (Spokesperson)

Administrative Coordination
Martina Piotrowski

Executive Committee
Prof. Adamantios Arampatzis
Prof. Georg Duda
Prof. Marc Kraft
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Scientific Advisory Board
Prof. Vasilios Baltzopoulos (GBR)
Prof. Walter Herzog (CAN)

General Information

Venues

Lectures will take place from Monday 7th until Friday 11th October.

Address (map at page 33).

Humboldt-Universität zu Berlin
Department of Training and Movement Sciences
Philippstr. 13, Haus 11
Lecture Hall 5 (Room 1.26)
10115 Berlin
Web: www.dtms.hu-berlin.de

The Wi-Fi network eduroam (education roaming) is available at the venue. Students, researchers and staff can obtain Internet connectivity across the campus using the respective institutional credentials.

Supported by

General Information
The Autumn School and the BSMS

The Berlin School of Movement Science (BSMS) is an interdisciplinary education programme based on scientific exchange and interaction, supporting PhD students to become highly skilled scientists in the fields of motor control and movement science. Our main research objectives are:

(a) to acquire knowledge about the fundamental principles of motor control in human movement,
(b) to investigate the effects of the musculoskeletal properties on the motor control strategies used during movement and
(c) to understand how the sensory-motor system controls biomechanical features and lead to adaptation on a structural level in tissues such as bone and muscle.

The BSMS organises yearly an International Autumn School on Movement Science for young scientists to give first-hand experience of the unique graduate training programme in the field of movement science.

In this Autumn School we want to provide an overview on movement and ageing from different perspectives such as the brain, central nervous system, muscle and tendon as well as the associated diseases and therapeutic options using physical activity.

The participation to the Autumn School is free of charge and is of particular interest to those Master's and PhD students who are considering doing their doctoral or post-doctoral research in the field of movement science within the BSMS network.

Sessions

Scientific Programme

Coffee breaks from 10:30 to 11:00 and from 14:30 to 15:00

Monday 7th October
Day 1

09:30 to 10:30 **Gerald Loeb** – *University of South Carolina, USA*
11:00 to 12:00 **Christian Rode** – *Friedrich Schiller University Jena, GER*
13:30 to 14:30 **Markus Böl** – *Technische Universität Braunschweig, GER*
15:00 to 16:00 **Boris Prilutsky** – *Georgia Institute of Technology, USA*

Tuesday 8th October
Day 2

09:30 to 10:30 **Alessandro Santuz** – *Dalhousie University, CAN*
11:00 to 12:00 **Mark Latash** – *Penn State University, USA*
13:30 to 14:30 **Shinya Aoi** – *Kioto University, JPN*
15:00 to 16:00 **Natalie Holt** – *University of California, Irvine, USA*

Wednesday 9th October
Day 3

09:30 to 10:30 **Nikolai Konow** – *University of Massachusetts Lowell, USA*
11:00 to 12:00 **Neil Cronin** – *University of Jyväskylä, FIN*
13:30 to 14:30 **Carolyn Eng** – *Yale University, USA*
15:00 to 16:00 **Shantanu Sinha** – *University of California, San Diego, USA*

Thursday 10th October
Day 4

09:30 to 10:30 **Rod Barrett** – *Griffith University, AUS*
11:00 to 12:00 **Mette Hansen** – *Aarhus University, DEN*
13:30 to 14:30 **Can Yucesoy** – *Bogazici University, TUR*
15:00 to 16:00 **Marco Narici** – *University of Padova, ITA*

Friday 11th October
Day 5

09:30 to 10:30 **Jens Bojsen-Møller** – *Norwegian School Sport Sciences, NOR*
11:00 to 12:00 **Franchi Martino** – *University of Padua, ITA*
13:30 to 14:30 **Abigail Mackey** – *Copenhagen University, DEN*
15:00 to 16:00 **Stéphane Baudry** – *Université Libre de Bruxelles, BEL*

Sessions

Social Programme

The students at the BSMS thought of organising a parallel social programme based almost exclusively on donations and free activities. For the paid options everybody is most welcome to to join but, unfortunatelly at your own expense. Please feel free to join us in any of the event planned for the Autumn School's week!

Monday 7th October

17:00 to 19:30 **Get-together party** (To be confirmed)
"Flora Cafe" in the Campus Nord
Philippstr. 13, Haus 10, 10115 Berlin

Wednesday 9th October

17:00 to 19:30 **Boat tour**
Weidendammer Brücke, 10117 Berlin
Cost € 20.00 please confirm your presence by Monday 7th
(v.munozmartel@hu-berlin.de)

Thursday 10th October

17:00 to 19:30 **Opera "Turandot" - Deutsche Oper Berlin**
Bismarckstraße 35, 10627 Berlin
www.deutscheoperberlin.de
Cost from € 24.00 please confirm your presence by Monday 7th (v.munozmartel@hu-berlin.de)

Friday 11th October

16:30 to 18:30 **A walk through history: the Berlin Wall**
Philippstr. 13, Haus 11, 10115 Berlin

19:00 **Festival of lights walk**
Berlin's world famous sights and monuments in the city centre become canvas for artful displays.
https://festival-of-lights.de/en/

20:30 **Farewell dinner - Brauhaus Südstern**

Hasenheide 69, 10967 Berlin Limited places available, please confirm your presence (v.munozmartel@hu-berlin.de)

Monday 7th October

Scientific Programme

Humboldt-Universität zu Berlin | Philippstr. 13, Haus 11 | Room 1.26

09:15 to 09:30	Welcome and introduction
09:30 to 10:30	Learning to use muscles **Gerald Loeb** – *University of South Carolina, USA*
10:30 to 11:00	Coffee break
11:00 to 12:00	Current View of Muscle Mechanics – Mechanisms and Models **Christian Rode** – *Friedrich Schiller University Jena, GER*
12:00 to 13:30	Break
13:30 to 14:30	Aspects of active muscle modelling - multi-scale/field modelling in biomechanics **Markus Böl** – *Technische Universität Braunschweig, GER*
14:30 to 15:00	Coffee break
15:00 to 16:00	Neuromechanical modeling of locomotion: A tool for understanding muscle and kinematic synergies **Boris Prilutsky** – *Georgia Institute of Technology, USA*

Monday 8th October

Abstracts

Learning to use muscles

Gerald Loeb – *University of South Carolina, USA*

To an engineer, vertebrate musculoskeletal systems appear to be gratuitously complex: more degrees of freedom than achievable postures, more muscles than degrees of freedom, muscles that act on more than one joint, force output strongly dependent on kinematics, slow and state-dependent responses to neural commands, proprioceptors with dynamically programmable gains, feedback controllers with long delays, etc. Researchers observe that, nevertheless, individuals of a given species tend to adopt similar patterns of muscle use when performing similar tasks. Researchers call such patterns "synergies" and interpret them in two ways: i) they might reflect fundamental limitations imposed by a restricted set of neural modules available to control the muscles; ii) they might reflect optimal control solutions computed by the nervous system for similar problems. Both interpretations overlook a biological interpretation that is more robust both ontogenetically and phylogenetically and can account for frequent exceptions to the common patterns.

Higher organisms learn to use their musculoskeletal systems in novel ways to deal with individual growth and development, often unpredictable environments, and mutations to their musculoskeletal systems that are the sine qua non of evolution. Between the brain (controller) and musculoskeletal system (plant) lies the spinal cord, an intricate piece of "programmable middleware" whose connectivity develops through the combination of highly choreographed developmental sequences and continuing system identification via motor babbling initially and systematic practice later. Most voluntary motor commands from the cerebral cortex are processed through this middleware rather than directly controlling the motoneurons that innervate individual muscles. The iterative process of learning a steadily growing repertoire of "good enough" behaviors accounts for both the correlated patterns extracted from behavioral data (i.e. the synergies) and the residual variances, which are often minimized by artful selection of the behaviors studied or overlooked entirely. The trophic responses of the musculoskeletal system that result from specialized training or rehabilitation are yet another manifestation of the power of design by evolution compared to design by engineering.

References

Loeb, G.E., Optimal isn’t good enough. Biological Cybernetics, DOI 10.1007/s00422-012-0514-6, 2012.

Tsianos, G.A., Goodner, J. and Loeb, G.E. Useful properties of spinal circuits for learning and performing planar reaches J. Neural Eng. 11 (2014) 056006 (21pp), doi: 10.1088/1741-2560/11/5/056006, 2014.

Monday 7th October
Abstracts

Current View of Muscle Mechanics – Mechanisms and Models

Christian Rode – Friedrich Schiller University Jena, GER

In this lecture I provide a brief biological overview on fundamental skeletal muscle mechanics and current theories of muscle contraction, with a focus on the work done by collaborators and myself. The overview includes dynamical 1-D behavior of muscle fibers and muscles and models thereof, as well as some results on 3-D muscle behavior.

Typically, skeletal muscles connect bones across joints. Muscle force is transferred via aponeuroses and tendon to the bone. Induced by electrical neural stimulation, muscles contract and power movements. Skeletal muscle is a massively cascaded actuator with motors in parallel and in series. The muscle consists of muscle fibers that are mostly arranged in parallel. These fibers contain parallel myofibrils. The myofibrils are made of hundreds to thousands of half-sarcomeres in series. Within half-sarcomeres, the contractile myofilaments actin and myosin are arranged in parallel. Actin filaments are anchored at the Z-disc and myosin filaments at the M-line. Connecting the two sets of myofilaments, titin anchors myosin filaments to the Z-disc which guarantees structural integrity when the muscle is pulled to long lengths. Here, titin delivers a considerable fraction of the passive muscle force (that includes forces by connective tissues surrounding the fibers, the fascicles and the whole muscle belly) [1].

The classic view is that muscles contract by pulling the regular sets of thick and thin filaments towards each other by the action of myosin heads. These heads project from the thick (myosin) filaments towards the thin (actin) filaments. Due to a rise of calcium concentration, actin filaments expose binding sites where the myosin heads connect cyclically (forming cross-bridges) in a stochastic process and pull. When simulating muscle force production, Hill-type models used in computer simulations of muscle-skeletal systems approximate the dynamics of the crossbridges by multiplying the phenomenological force-velocity and force-length relationships. Large parts of these relationships can be readily explained with the crossbridge [2] and sliding filament theories [3,4]. However, the force-length relationship is experimentally determined with isometric muscle experiments. One of the interesting experimental results is that in isometric followed by extensive isokinetic contractions, the muscle fibers act like a linear spring with adjustable rest length [5]. Force predictions of classic Hill models are not able to describe this and other effects.

I will present current theories of muscle contraction that potentially explain behavior of muscle fibers that seemingly contradict the established theories. On the one hand, titin seems to play an important role for force effects observed in active contractions in intermediate and long muscle lengths [6,7], while a theoretical sliding of myosin filaments through the Z-disc explains effects at short muscle lengths [8]. These theories complement the classic theories and enable a better description of the contractile behavior of the muscle. Since also 3D muscle models depend on the description of the half-sarcomeres, improvements on this level are fundamental for muscle research [9].

Muscles are constrained by other muscles and bones. The resulting transversal loading decreases muscle force along the line of action [10]. A simple extension of a Hill-type model can represent the deformation and force effects for a limited range of transversal loads [11]. The sources of the force decrease are unclear; hydrostatic effects are not sufficient to explain the phenomenon [12]. Developing accurate 3D muscle models that can be used to elucidate the underlying mechanisms or e.g. the intricate role of the aponeurosis in muscle contractions requires comprehensive datasets (fiber lengths and angles of pennation, dynamic muscle parameters). First data are available [13], and first continuum-mechanical muscle models have been developed that include a titin mechanism [14, 15].

References

[1] Prado LG, Makarenko I, Andresen C, Kruger M, Opitz CA & Linke WA. (2005). Isoform diversity of giant proteins in relation to passive and active contractile properties of rabbit skeletal muscles. J Gen Physiol 126, 461-480.

[2] Huxley AF. (1957). Muscle structure and theories of contraction. Prog Biophys Biophys Chem 7, 255-318.

[3] Huxley AF & Niedergerke R. (1954). Structural changes in muscle during contraction; interference microscopy of living muscle fibres. Nature 173, 971-973.

[4] Huxley HE & Hanson J. (1954). Changes in the cross-striations of muscle during contraction and stretch and their structural interpretation. Nature 173, 973-976.

[5] Tomalka A, Rode C, Schumacher J, Siebert T (2017) The active force-length relationship is invisible during extensive eccentric contractions in skinned skeletal muscle fibres. Proc Roy Soc B, 284:20162497

[6] Rode C, Siebert T & Blickhan R (2009) Titin induced force enhancement and force depression: A ‘sticky spring’ mechanism in muscle contractions? J Theor Biol 259: 350–360.

[7] Nishikawa KC, Monroy JA, Uyeno TE, Yeo SH, Pai DK & Lindstedt SL. (2012). Is titin a 'winding filament'? A new twist on muscle contraction. Proc Biol Sci 279, 981-990.

[8] Rode C, Tomalka A, Blickhan R & Siebert T (2016) Myosin filament sliding through the Z-disc relates striated muscle fibre structure to function. Proc Roy Soc B, 283:20153030.

[9] Siebert T & Rode C (2014) Computational modeling of muscle biomechanics. In: Computational Modelling of Biomechanics and Biotribology in the Musculoskeletal System, 1st Edition edited by Z Jin, 173-204; Woodhead Publishing - Elsevier, ISBN: 9780857096616

[10] Siebert, T., Till, O., Stutzig, N., Gunther, M., & Blickhan, R. (2014b). Muscle force depends on the amount of transversal muscle loading. J Biomech, 47 (8), 1822-1828.

[11] Siebert T, Stutzig N, Rode C (2018) A hill-type muscle model expansion accounting for effects of varying transverse muscle load. J Biomech, 66:57-62

[12] Siebert, T., Rode, C., Till, O., Stutzig, N., & Blickhan, R. (2016). Force reduction induced by unidirectional transversal muscle loading is independent of local pressure. J Biomech 49 (7), 1156 1161.

[13] Siebert T, Leichsenring K, Rode C, Wick C, Stutzig N, Schubert H, Blickhan R & Böl M (2015) Three-dimensional muscle architecture and comprehensive dynamic properties of rabbit gastrocnemius, plantaris and soleus: input for simulation studies PLOS One, 10(6): e0130985.

[14] Heidlauf T, Klotz T, Rode C, Siebert T, & Röhrle O. (2017). A continuum-mechanical skeletal muscle model including actin-titin interaction predicts stable contractions on the descending limb of the force-length relation. PLOS Computational Biology, 13(10): e1005773.

[15] Heidlauf T, Klotz T, Rode C, Altan E, Bleiler C, Siebert T & Röhrle O (2016) A multi-scale continuum model of skeletal muscle mechanics predicting force enhancement based on actin-titin interaction. Biomech Model Mechanobiol, 15:1423-1437. doi 10.1007/s10237-016-0772-7.

Monday 7th October
Abstracts

Aspects of active muscle modelling - multi-scale/field modelling in biomechanics

Markus Böl – *Technische Universität Braunschweig, GER*

From the mechanical perspective, biological structures are usually characterised by complex, structural systems, challenging material properties, and highly effective as well as optimised functionalities. Additionally, biological tissues are living and thus growing systems whose macro and microstructures are inferior to continuous changes. In case of skeletal muscles, their special feature it their ability to contract based on an electrical stimulus and thus to generate active forces.

Within this talk a three-dimensional multi-scale/field skeletal muscle modelling approach will be presented, able to link mechanical and structural information across different length scales. The predictive success of the modelling approach depends not insignificantly on the experimental information at the various length scales. Consequently, the aim of this talk is two-part: On the one hand, a three-dimensional modelling concept will be presented able to describe the active and passive muscle mechanics from fibre to muscle level. On the other hand, comprehensive (mechanical and structural) experiments will be presented and discussed to understand muscle mechanics at different length levels, to calibrate and to validate the modelling concept. Consequently, structure-based load transfer mechanisms within skeletal muscles will be discussed in detail.

Through the combination of experimental investigations, the resulting understanding of load transfer mechanisms, the linkage of various scientific disciplines, and modelling approaches developed from this, it will be possible in the future to transfer biology-structure-based statements to questions of engineering and to answer questions at the interface of human medicine.

Monday 7th October

Abstracts

Neuromechanical modeling of locomotion: A tool for understanding muscle and kinematic synergies

Boris Prilutsky – *Georgia Institute of Technology, USA*

For over a century movement scientists have argued that complex movements, including locomotion, are constructed from relatively simple and independent movement elements. Movement science literature has referred to such elements as reflexes, coordinative structures, engrams, or synergies. Substantial progress has been made over the years in identifying potential muscle and kinematic synergies using experimental and computational methods. Recordings of activity of multiple neurons and muscles, as well as kinematics of multiple body segments with the subsequent data dimensionality reduction have confirmed that observed activity and movement patterns in different motor behaviors can be described by a relatively small number of muscle and kinematic synergies. What is still unknown is which structures of the nervous system underlay the observed synergies, how these structures are organized and controlled. Recent studies in genetically modified mice have started addressing the above questions experimentally. Our group uses a complimentary modeling approach to understand better the formation of muscle and kinematic synergies during locomotion. We with our colleagues have developed a comprehensive neuromechanical model of cat hindlimb locomotor control. After tuning model parameters, the model reproduces locomotor mechanics, muscles activity patterns and activity patterns of some muscle and skin afferents, and the muscle and kinematic synergies derived from our experimental studies. By modifying the structure of the locomotor rhythm generating networks and the gains in sensory pathways of the model, we analyze the corresponding changes in the muscle and kinematic synergies. Our computational studies suggest that the major muscle and kinematic synergies of level locomotion are formed by the spinal rhythm generator and pattern formation networks, as well as by the somatosensory feedback. Supraspinal inputs are necessary to explain muscle synergies during slope locomotion.

Tuesday 8th October
Scientific Programme

Humboldt-Universität zu Berlin | Philippstr. 13, Haus 11 | Room 1.26

09:30 to 10:30	Robust vertebrate locomotion in challenging settings **Alessandro Santuz** – *Dalhousie University CAN*
10:30 to 11:00	Coffee break
11:00 to 12:00	Controlled Stability of Action by Motor Synergies **Mark Latash** – *The Pennsilvania State University, USA*
12:00 to 13:30	Break
13:30 to 14:30	Neuromusculoskeletal models based on the muscle synergy hypothesis for understanding adaptive motor control in locomotion **Shinisha Aoi** – *Kyoto University, JAP*
14:30 to 15:00	Coffee break
15:00 to 16:00	Crossbridge-compliance interactions: implications for muscle physiology and organismal performance **Natalie Holt** – *University of California, Irvine, USA*

Tuesday 8th October

Abstracts

Robust vertebrate locomotion in challenging settings

Alessandro Santuz – *Dalhousie University, CAN*

In our daily life, we constantly face various kinds of perturbations that challenge our ability to move. Typical disturbances to locomotion from external sources might be changes in terrain's morphology, such as the unevenness of a rough mountain trail, or alterations of available friction, which is what happens when we unexpectedly step on an invisible layer of ice in winter. Examples of internal sources of instability are ageing and the implied constraints to mobility, or the pathology-related loss of the ability, called proprioception, to sense the position of own body parts. Despite the vastness of available scientific literature, how the CNS arranges the coordination of hundreds of muscles and joints remains a largely unanswered question. A recent theory based on classical neuroscience observations from the first half of the twentieth century states that the CNS might not be controlling each muscle and joint individually. Rather, it might be generating a handful of activation patterns, common to those muscle groups needed to complete a specific task. These modular control signals have been called muscle synergies.

In this presentation, I will review our experiments on both humans and mice that used perturbations to emphasise the modular control strategies adopted by the CNS to deal with disruptions of locomotion. In a first introductory section, I will present the mathematical underpinning of the muscle synergies theory, through step-by-step elucidations and examples from real data. Moreover, I will lay the foundations of chaos theory necessary to understand how it is possible to assess the stability over time of muscle synergies, discussing the concept of Lyapunov exponent. Then, I will proceed to show how muscle synergies can be used to evaluate the modular organisation of vertebrate locomotion. After illustrating the characteristic output obtainable from healthy adults during treadmill walking and running, I will show how muscle synergies are tuned in the presence of internal and external perturbations to locomotion. In the final section, I will describe the effects of the acute and chronic genetic removal of proprioceptors on murine locomotion. Here, I will demonstrate that there can be translation from mice to humans when considering muscle synergies and their stability over time in the presence and absence of sensory feedback and/or mechanical perturbations.

Tuesday 8th October
Abstracts

Controlled Stability of Action by Motor Synergies

Mark Latash – *The Pennsylvania State University, USA*

Dynamic stability is an essential feature of natural movements given the unpredictable environment and time-varying intrinsic states of the body. Stability has to be controlled in a task-specific way given that salient performance variables differ across tasks and that excessive stability potentially creates problems for quick action initiation.

Recent theoretical developments within the physical/physiological approach, such as the principle of abundance, the uncontrolled manifold hypothesis, and the theory of hierarchical control with spatial referent coordinates for moving effectors, have resulted in several methods of analysis of action stability. I will review briefly the theoretical framework of this approach, and some of the recent findings that quantified stability-related phenomena across tasks, spaces of elemental variables, and populations. These will include the concepts of ascending and descending synergies, anticipatory synergy adjustments, and causes of unintentional drifts in performance.

Clinical studies have shown that neurological impairments are frequently associated with a syndrome termed "impaired control of stability", which consists of two components: Impaired stability and impaired agility. The two components are sensitive to very early, preclinical, stages of Parkinson's disease, as well as to a number of other subcortical disorders. The two components show different sensitivity to treatment, such as deep brain stimulation and dopamine-replacement drugs. They may be differentially affected by stroke.

Overall, this conceptual scheme offers a novel view on the neural control of redundant (actually, abundant!) sets of effectors, which promises direct clinical applications.

Tuesday 8th October

Abstracts

Neuromusculoskeletal models based on the muscle synergy hypothesis for understanding adaptive motor control in locomotion

Shinisha Aoi – *Kyoto University, USA*

Humans and animals walk adaptively by skillfully manipulating complicated and redundant musculoskeletal system. The analysis of measured EMG data has shown that the combination of a few basic waveforms reproduces a large portion of the EMG data. Moreover, such muscle synergy analyses have provided further low-dimensional structures for locomotor tasks. For example, the EMG patterns in running are explained by phase shift of one basic waveform of walking. The EMG patterns during voluntary movements in walking, such as stepping over an obstacle, are explained by the superposition of basic waveforms for normal walking. Stroke sufferers reduce motor performance through merging some basic waveforms and the merged waveforms are split into multiple waveforms in the post-stroke recovery to improve the motor performance. In the development from neonate to adult, the number of basic waveforms increases and the waveform shapes change to achieve effective locomotion. Furthermore, similar low-dimensional structures appear in animals, such as rats, cats, and monkeys, despite substantial phylogenetic distances and morphological differences. These findings suggest that motor control in humans and animals utilizes such low-dimensional structures to solve the motor redundancy problem and to achieve locomotor functions.

Although physiological studies have provided meaningful insights for the underlying neural mechanisms, it is difficult to fully clarify them only from experimental data. Because locomotion is well-organized motion generated through dynamic interactions between the motor control system, musculoskeletal system, and environment, we focus on modeling studies to investigate the neural mechanisms, where we develop motor control models based on physiological hypotheses and integrate them with musculoskeletal models. In this talk, I will present neuromusculoskeletal models of humans and animals based on the muscle synergy hypothesis for understanding adaptive motor control in locomotion.

Tuesday 8th October
Abstracts

Crossbridge–compliance interactions: implications for muscle physiology and organismal performance

Natalie Holt – University of California, Irvine, USA

Skeletal muscle is the biological motor. Crossbridge interactions between the contractile proteins actin and myosin convert chemical energy in the form of ATP into the mechanical output required for movement. However, a complex force transmission pathway exists between actin and myosin and the environment; contractile proteins are organized into sarcomeres and fibers, and connected to bone by aponeuroses and tendons. Many elements of this pathway exhibit compliance, and can therefore affect muscle and organismal performance. Long distal tendons undergo significant deformations during locomotion, and so can decouple muscle fiber length changes from joint rotations and mechanical energy fluctuations.

In level running force must be generated to support bodyweight, and mechanical energy fluctuations accommodated. These demands may be met by muscle actively stretching and shortening, or by muscle contracting isometrically and tendon stretching and recoiling. The latter strategy is observed in the distal limbs of cursorial species, and is thought to conserve metabolic energy by reducing the need for muscle to actively shorten and do work. However, the assumption that muscle work is costly comes from tightly controlled contractions in muscles from model organisms, and may not be broadly applicable. We have demonstrated that muscles incur similar costs during stretch-shorten and isometric contractions. This finding raises questions about both the role of work minimization by tendons and our understanding of crossbridge cycling. Work minimization by tendons has been used to explain how locomotor efficiency can exceed the assumed ~25% efficiency of muscle. However, the similarity of cost in stretch-shorten and isometric contractions, along with other findings, suggest that tendon may not be necessary to explain this. Although the mechanisms responsible are unclear, muscle efficiency appears to vary across species and with length and activation dynamics, often exceeding 25%.

Wednesday 9th October
Scientific Programme

Humboldt-Universität zu Berlin | Philippstr. 13, Haus 11 | Room 1.26

09:30 to 10:30	Muscle tendon interactions: Beyond power amplification **Nicolai Konow** – *University of Massachusetts Lowell, USA*
10:30 to 11:00	Coffee break
11:00 to 12:00	MTU analysis methods: Past, present and future **Neil Cronin** – *University of Jyväskylä, FIN*
12:00 to 13:30	Break
13:30 to 14:30	Muscle Related Connective Tissues Affect Muscular Force Production **Carolin Eng** – *Yale University, USA*
14:30 to 15:00	Coffee break
15:00 to 16:00	Structure-Functional Modeling of the Normal and Atrophied (Unilateral Limb Suspension and Aging) Human MSK System Using Novel MR Imaging Techniques **Shantanu Sinha** – *University of California, San Diego, USA*

Wednesday 9th October

Abstracts

Muscle tendon interactions: Beyond power amplification

Nicolai Konow – *University of Massachusetts Lowell, USA*

For more than half a Century, we have known that skeletal joint mechanics result not only from the contractile action of muscle motors (sarcomeres at the sub-cellular level), but also from interactions between muscle motors and compliant connective tissue with elastic properties. Recently, however, we have gained a much deeper appreciation of how the elastic stretch and recoil of muscle-tendon units substantially broaden the functional repertoire of muscles as they generate, sustain, and halt skeletal movements. By far the best studied, and hence the most commonly known role for connective tissue springs is in power amplification, where the rapid shortening velocities of recoiling tendon, which often substantially exceeds those of muscle in shortening contractions (approx. 12-15 resting lengths per second) causes amplification of the mechanical power (force x velocity) available for accelerating and sustaining joint movement. Our recent work has used turkey drop-landings and down-hill running as model systems to explore the inverse of power amplification, namely power attenuation. In power attenuation, the energy flow is reversed; flowing from the environment, via tendon, to the muscle. Faster stretch of tendon than muscle diminishes the instantaneous energy flow to the muscle for dissipation via active lengthening. This provides a shock-absorbing effect that protects against stretch-induced muscle injury and ensures safe deceleration, and stopping.

From a materials and mechanical perspective, the comparative literature suggest tendon to be a functionally homogeneous tissue with relatively fixed modulus, hysteresis, and thus capacity for energy storage and return. Whether comparatively stiff or not, our recent work shows that tendon provides several other – much less recognized – functional advantages than power amplification. Our work on bat wing and the salamander jaw movements demonstrates roles for tendon-mediated speed-amplification. This more fundamental amplification version likely offers important evolutionary advantages to organisms as they move to feed, or to avoid becoming fed upon: In the bat wing, umbrella-like elbow actuation resulting from the biceps muscle-tendon unit mainly acting as a stiff position controller, while the triceps muscle-tendon unit acts like a compliant force controller. Tendon testing reveals clear gradients, from proximal to distal, and between elbow and wrist flexors and extensors in tendon mechanical properties, thus challenging the paradigm of homogenous properties. Similarly, in the salamander jaw system, spring-like action of muscle-tendon units amplify the speed of jaw movement, which may be linked to evolutionary advantages in prey-escape avoidance. Elastic action can redistribute the production of muscle force and work to opportune phases of a given movement cycle. For example, in the bat wing, triceps shortens as the aerodynamic wing load is low, and at the end of down-stroke, energy is harvested as tendon stretch due to rotational inertia. Overall, these processes result in a reduction in the requirement for muscle mechanical work by approx. 20%.

Other important benefits from series elastic action in the bat wing include overextension prevention and antagonist shortening for modulating joint stiffness. Our comparative studies also reveal that force enhancement from eccentric contractions is widespread and in the presence of elastic elements, this phenomenon can drastically increase storage and return of mechanical energy in the system. Finally, elastic action occurs not only in free tendon, but also in the aponeurotic tendon sheets that encase muscle. Our recent work provides exciting evidence to suggest that the anisotropic properties of these helically woven collagenous sheets provides a mechanism for tuning the capacity for elastic storage and return and dynamically modulate tendon spring function during in vivo movements. We expect our future comparative studies to continue to broaden our understanding of how tendons allow for many more mechanical functions than amplifying the power of muscle contractions and body movement.

Wednesday 9h October

Abstracts

MTU analysis methods: past, present and future

Neil Cronin – *University of Jyväskylä, FIN*

In the past few decades, ultrasound imaging has been used extensively to examine muscle and tendon function. Technological improvements have even made it possible to perform such measures in dynamic conditions like running and jumping. However, ultrasound images are still of a relatively poor quality compared to other imaging modalities, and analysis of these images has traditionally relied on subjective interpretation. This is both time consuming and prone to human error/bias.

In this talk I will first give an overview of the manual analysis process, highlighting the challenges of this approach. I will then introduce some attempts to semi-automate the process. These approaches require some degree of user input, for example, labelling certain features in the first frame of a video, and then relying on an algorithm to continue the analysis process. Semi-automated approaches offer a flexible way to analyse data, giving the user more control over the output, but because of this, it is also difficult to quantify the time savings that they might offer, e.g. in cases where a lot of manual correction is required. Moreover, semi-automated methods are still prone to the same sources of error (e.g. bias) as fully manual methods.

In the final part of my talk, I will introduce attempts to fully automate the process of analysing ultrasound images, with a particular emphasis on methods that exploit artificial intelligence principles. This will include recent examples that used deep learning to analyse a range of parameters relevant to the study of muscle-tendon unit function.

Wednesday 9h October

Abstracts

Muscle Related Connective Tissues Affect Muscular Force Production

Carolin Eng – *Yale University, USA*

Energy storage and recovery in connective tissues reduces muscle work and makes movement more efficient. While energy storage is mostly investigated in tendons, I present evidence that intramuscular connective tissues (IMCTs) and fascia store and recover substantial elastic energy and potentially play an important and largely unexplored energy storage role during movement.

IMCTs are typically assumed to play a limited energy storage role but using a simple model validated with in vivo muscle shape change recordings, I show that IMCT energy storage may be substantial. In the model, IMCT is perpendicular to the muscle line of action and is compressed by fiber forces. Modeling results were validated with in vivo biplanar fluoroscopy recordings of locomoting turkeys whose muscles were implanted with radiopaque beads. Both modeling results and in vivo data showed muscle lengthening and shortening, indicating energy absorption and recovery. Because the muscle fibers underwent limited length change, muscle length change was accommodated in part by changes in fiber rotation and muscle thickness, suggesting energy cycling in the thickness direction. Calculations of thickness work show that thickness energy cycling is potentially substantial.

Fascia is closely associated with muscle and its energy storage role is not well understood. The human iliotibial band (ITB) is a large piece of fascia on the lateral thigh that is the insertion site for two important hip muscles. I used biomechanical measurements on human limbs to modify a lower limb musculoskeletal model to more accurately represent ITB anatomy. Using the model to compute loading and stretch of the ITB during running, I found that the ITB has the potential to store and recover a significant amount of elastic energy. Long recognized as morphologically diverse, my work demonstrates that a variety of connective tissues play important energy storage roles through diverse mechanisms.

Wednesday 9h October

Abstracts

Structure-Functional Modeling of the Normal and Atrophied (Unilateral Limb Suspension and Aging) Human MSK System Using Novel MR Imaging Techniques

Shantanu Sinha – *University of California, San Diego, USA*

MRI, with its excellent soft-tissue contrast, non-ionizing and non-invasive nature, has become one of the most powerful radiologic imaging modality, enabling unique voxel-based multi-parametric in vivo mapping of the human MSK system over large field-of-views. We will first present studies of static properties such as (1) muscle structure, including shape and size using high-resolution MRI, (ii) fiber architecture such as fiber length and pennation angles and microarchitecture of the fiber/ endomysium, from Diffusion Tensor Imaging (DTI) and (iii) tissue composition e.g. adipose tissue, fibro-cartilaginous extracellular matrix using Ultrashort-TE (UTE) imaging. We will next focus on (iv) Dynamic (using Velocity-Encoded Phase-Contrast (VE-PC)) MR imaging which maps muscle tissue velocity (and strain) while executing either passive, isometric, concentric or eccentric contractions, using a computer-controlled, MR compatible system. Implementation of novel "compressed sensing" approaches decreases scan times significantly, allowing studies at higher MVC's in shorter times. Thereby, "weak" (e.g. senior) subjects can be studied. Strain rate tensors and shear strain can be extracted from the VE-PC images. The hypothesis that the shear strain may reflect the remodeling of the ECM with aging will be discussed. We have applied the combination of the above MRI approaches to comprehensively assess muscle structure and function in normal humans and the changes concomitant with acute atrophy (by ULLS) and chronic atrophy from aging. Our studies reveal that correlation between these indices and force loss in both ULLS and aging muscle systems enables one to quantitate potential contributions to loss of muscle quality from changes in muscle architecture, fiber-microstructure and modulation of the extracellular matrix. We will conclude with our future/ongoing work on validation of these MR measurements with muscle biopsy histological analysis and computational modeling.

Thursday 10th October

Scientific Programme

Humboldt-Universität zu Berlin | Philippstr. 13, Haus 11 | Room 1.26

09:30 to 10:30	Targeted Achilles tendon training and rehabilitation **Rod Barrett** – *Griffith University, AUS*
10:30 to 11:00	Coffee break
11:00 to 12:00	Influence of gender and female hormones on tendon and ligaments **Mette Hansen** – *Aarhus University, DEN*
12:00 to 13:30	Break
13:30 to 14:30	Muscle Related Connective Tissues Affect Muscular Force Production **Can Yucesoy** – *Bogazici University, TUR*
14:30 to 15:00	Coffee break
15:00 to 16:00	Muscle and tendon adaptations to chronic loading and unloading **Marco Narici** – *University of Padova, ITA*

Thursday 10th October

Abstracts

Targeted Achilles tendon training and rehabilitation

Rod Barrett – *Griffith University, AUS*

Musculoskeletal tissues, including tendon, are sensitive to their mechanical environment, with both excessive and insufficient loading resulting in reduced tissue strength. Tendons appear to be particularly sensitive to mechanical strain, and there appears to be an optimal tendon strain that results in the greatest positive tendon adaptation. The main propositions of this presentation are that (1) the Achilles tendon can experience positive adaptation when exposed to strains within a specific range or 'sweet spot', (2) in vivo Achilles tendon strain depends on many factors known to differ between individuals and (3) new, integrated technologies that account for these interindividual differences and provide real-time feedback of Achilles tendon strain are within reach and will take some of the guesswork out of training and rehabilitation by ensuring tendon strains (magnitude, duration, frequency and rate) occur within the range that elicit maximal tendon adaptation. Unfortunately, direct measurement of in vivo Achilles tendon strain during functional tasks, such as ambulation, is difficult. The proposed approach to assessing in vivo tendon strain in the practical setting instead involves combining tendon imaging, wearable sensors and personalised computational models (rigid body neuromusculoskeletal and finite element). Such technology would connect, across size scales, knowledge from two previously distinct areas of science, that is, mechanobiology of isolated tendons and whole-body biomechanics, and offer a new approach to Achilles tendon rehabilitation and training. An overview of the proposed approach and some preliminary data will be presented.

Thursday 10th October

Abstracts

Influence of gender and female hormones on tendon and ligaments

Mette Hansen – *Aarhus University, DEN*

Gender difference is observed in regards to connective tissue, which may be linked partly to a differential sex hormonal profile. The effect of female hormones on skeletal muscle connective tissue is a puzzle. Endogenous and exogenous administrated estradiol seems to influence the tendon and ligament mechanical properties differently. The latter may be related to a combination of direct and indirect hormonal effects. This presentation will add pieces to the puzzle by showing results from primarily human cross-sectional trials and randomized controlled interventions trials, which have aimed to elucidate effects of estrogen and oral contraceptives on connective tissue protein turnover, tissue composition and biomechanical properties. Results have shown that tendon collagen synthesis rate is markedly lower in women compared to men both at rest and in response to acute exercise. Furthermore, cross-sectional data indicate that the hypertrophic effect of regular exercise on patellar and Achilles tendon is reduced in young trained women compared to similarly trained men. Use of oral contraceptives seems to reduce tendon and muscle connective protein synthesis rate in young women and enhance tissue stiffness. In contrast, administration of estrogen replacement therapy to elderly hysterectomized women seems to result in higher tendon collagen synthesis rate and relatively lower tendon stiffness. The divergent observations in young and elderly women may be explained by age differences per se and/or e.g. that use of oral contraceptives is associated with markedly lower IGF-I levels in young women.

Thursday 10th October

Abstracts

Muscle Related Connective Tissues Affect Muscular Force Production

Can Yucesoy – *Bogazici University, TUR*

Skeletal muscle is the motor for joint movement and is comprised of contractile elements and connective tissue. Sarcomere is the basic force-producing component, which contains the contractile elements, and in their arrangement in the level of muscle fibers, sarcomeres are surrounded by connective tissue. This description of muscle structure agrees well with the observed general morphology and distinguishes the roles of these main constituents as force production and protective packaging, respectively. Protective packaging role of the connective tissues has been also considered to be a central determinant for the muscle's passive resistance to stretch. However, a unique consideration is to ascribe muscle related connective tissues a role in 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 during joint movement will stretch muscle related connective tissues leading to myofascial loads to develop, which through the mentioned connectivity can manipulate sarcomere lengths within the muscle fibers. This mechanism consequently, can directly influence muscular force production, but also can affect connective tissue adaptation as these loads can affect fibroblasts' functioning. The talk will describe this mechanism based on several methodologies including animal experiments, finite element modeling, magnetic resonance imaging and intraoperative experiments, and show examples illustrating major clinical relevance.

References

Kaya et al., Clin Biomech, 68, 151-157, 2019
Karakuzu et al., J Biomech 57, 69-78, 2017
Ates & Yucesoy, Muscle Nerve 49, 866-878, 2014
Yucesoy, Exercise Sports Sci Rev 38, 128-134, 2010

Friday 11th October
Scientific Programme

Humboldt-Universität zu Berlin | Philippstr. 13, Haus 11 | Room 1.26

09:30 to 10:30	Eccentric loading, -would the tendon know? **Jens Bojsen-Møller** – *University of Southern Denmark, DEN*
10:30 to 11:00	Coffee break
11:00 to 12:00	From molecules to morphology and function: An overview of skeletal muscle adaptations to eccentric loading **Martino Franchi** – *University of Padua, ITA*
12:00 to 13:30	Break
13:30 to 14:30	Human skeletal muscle connective tissue during myofibre repair and at the myotendinous junction **Abigail Mackey** – *Copenhagen University, DEN*
14:30 to 15:00	Coffee break
15:00 to 16:00	Implication of age-related changes in leg proprioception for postural control **Stéphane Braudry** – *Universite Libre de Bruxelles, BEL*

Social Programme

16:30 to 18:30	**A walk through history: the Berlin Wall** Philippstr. 13, Haus 11, 10115 Berlin
19:00	**Festival of lights walk** Berlin's world famous sights and monuments in the city centre become canvas for artful displays. https://festival-of-lights.de/en/
20:00	**Farewell dinner** Brauhaus Südstern Hasenheide 69, 10967 Berlin The places for this event are limited. Please confirm your presence to the team (v.munozmartel@hu-berlin.de).

Friday 11th October

Abstracts

Eccentric loading, -would the tendon know?

Jens Bojsen-Møller – *University of Southern Denmark, DEN*

During human movement, the muscle and tendinous structures interact as a mechanical system in which forces are generated and transmitted to the bone. Hereunder, energy may be stored and released to optimize function, economy of movement and performance or to reduce risk of injury.

The in vivo loading of the passive force transmitting tissues i.e. tendon, aponeurosis and intramuscular connective tissue have been studied intensively in later years, and especially developments in in vivo imaging techniques with increasing resolution have taken this field of study forward. It is clear that force transmission mechanics is complex in muscle groups of especially the lower limbs, where separately activated muscles are mechanically connected longitudinally and transversely through connective tissue structures such as aponeuroses, fascia and tendon. The loading of these structures and their associated deformation is more intricate during human locomotion than previously thought, and increased understanding will ultimately yield description of potential mechanisms for function and/or tissue dysfunction.

The present talk addresses aspects of how the anatomical design and mechanical and material properties of the force transmitting tissues (mainly the triceps surae and the associated Achilles tendon) contributes to the function of the muscle-tendon unit. The force bearing tissues are examined mainly from a structural macroscopic point of view, where e.g. tendon rotation and intratendinous tissue sliding are described, but also mechanics at the nanoscale level of the collagen fibril is presented. Implications for overall muscle-tendon unit function, performance are mentioned and lastly the question of whether passive tissues are loaded differently during eccentric versus concentric muscle contractions is discussed since it may have relevance for injury mechanisms and rehabilitation strategies.

Friday 11th October

Abstracts

From molecules to morphology and function: An overview of skeletal muscle adaptations to eccentric loading

Martino Franchi – *University of Padua, ITA*

Based on lengthening muscle actions and production of negative work, eccentric contractions are regarded as a unique contraction modality from both the laboratory and clinical perspective. When compared to other types of contraction, such as concentric or isometric, eccentric actions present some peculiarities: not only they may generate greater maximal force/tension and with lower metabolic cost for the same work produced, but when used in training scenarios, they tend to be more effective to stimulate gains in muscle strength and lead to distinct regional hypertrophy and muscle architectural remodelling. Furthermore, it appears that such different morphological adaptations are regulated by distinct molecular and metabolic pathways, which may be contraction-specific.

The purpose of this talk is to provide a thorough overview of what we know up to now regarding such eccentric-specific adaptations. The aim is trying to unravel the molecular mechanisms that may lie behind the strategies of muscle structural remodelling in response to different modalities of eccentric exercise.

Friday 11th October

Abstracts

Human skeletal muscle connective tissue during myofibre repair and at the myotendinous junction

Abigail Mackey – *Copenhagen University, DEN*

Acute damage to the tendon and its attachment to skeletal muscle occurs in relation to occupational work, leisure activity and sports, and approximately 40% of all individuals will at some point in their life experience an acute musculo-tendinous injury [1]. This injury occurs in the interface between the muscle and the tendon – the myotendinous junction (MTJ) – and is associated with substantial injury recurrence. In fact individuals who have at some point sustained a strain injury have a 7-fold greater risk of injury than those who have never been injured before [2], indicating poor understanding of MTJ tissue repair mechanisms at the cellular and molecular level. This tissue site represents the meeting of one tissue rich in cells with little matrix (muscle) and the other tissue rich in matrix with few cells (tendon). With force transmission being transferred between these two tissues with completely different mechanical properties, perhaps it is not surprising that this is the weakest link. Similarly, while the role of the connective tissue matrix surrounding the individual muscle fibres is well established with regard to force transmission, crosstalk between the matrix and myofibres remains relatively unexplored. This presentation will address the composition of the human muscle-tendon interface [3] and the plasticity of muscle connective tissue in response to loading as well as during muscle regeneration [4]. Cell-cell interaction between fibroblasts and myoblasts will also be covered.

References

[1] Thomopoulos S, et al. (2015). J Orthop Res 33, 832-839.

[2] Arnason A, et al. (2004). Am J Sports Med 32, 5S-16S.

[3] Jakobsen JR, et al. (2018). Scand J Med Sci Sports 28, 1859-1865.

[4] Mackey AL, et al. (2016). FASEB J 30, 2266-2281.

Friday 11th October

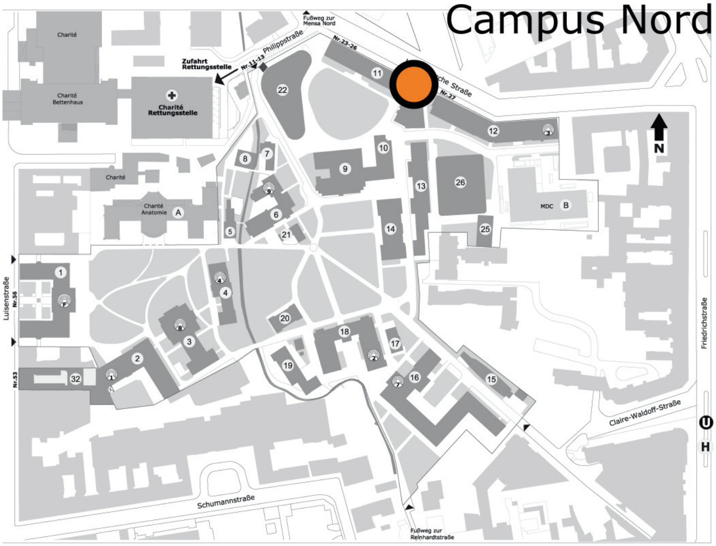
Abstracts

Implication of age-related changes in leg proprioception for postural control

Stéphane Braudry – *Universite Libre de Bruxelles, BEL*

Among hominid species, the natural bipedal erected posture is one of the most remarkable biomechanical characteristics of human beings. It can be modelled as an inverted pendulum rotating around the ankle joint with the intended equilibrium position being a slight forward tilt of the body, generating a gravity-driven instability. An active neural control through the integration of inputs arising from vestibular system of the inner ear, vision, and proprioception is necessary to maintain upright standing. Therefore, in addition to being a prerequisite for many activities of daily living, the ability to maintain steady upright standing is a relevant model to study sensorimotor integrative function. There is a general agreement that proprioception signals from leg muscles provide the primary source of information for postural control. However, aging is associated with alterations of muscle spindles and their neural pathways, which induces a decrease in the sensitivity, acuity and integration of the proprioceptive signal. These alterations promote changes in postural control that reduce its efficiency and thereby may have deleterious consequences on the functional independence of an individual. Considering the increasing percentage of the world population over the age of 60 years, a better understanding of the effect of age on leg proprioception and its implication in postural control is of paramount relevance. This talk provides an overview of how aging alters the proprioceptive signal from the legs, and presents compelling evidence that these changes modify the neural control of upright standing.

Lecture hall location
Campus Nord



Address and GPS coordinates

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52°31'36.8"N 13°23'00.7"E

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Berlin, 7th to 11th October 2019

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