Progress in Motor Control IX

Montreal, July 13-16, 2013

Program and abstracts / Programme et abrégés

13-16 July / juillet 2013
Montréal
Canada

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NeuroDevNet

Exhibitors / Exposants

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Program

Saturday July 13, 2013

Registration 12:00—13:30

Advances in Cerebral Palsy Research: From Cell to Community

Chairs: Carol L. Richards, Université Laval Research Chair in Cerebral Palsy, Quebec & Annette Majnemer, McGill University, NeuroDevNet, NCE

13:30-13:45	Opening remarks	*Annette Majnemer and Carol Richards*
13:45-14:30	Cerebral Palsy: Medical Advances from Cell to Community	*Michael Shevell, MD, CM, McGill University*
14:30-15:15	The Potential for Stem Cell Therapies to Have an Impact on Perinatal Neurological Injury – the Hype, the Hope and the Reality	*Crystal Ruff, PhD, Toronto Western Hospital*
15:15-15:45	*Health Break*	
15:45– 16:30	Non-Invasive Brain Stimulation to Understand and Enhance Function in Hemiparetic CP	*Adam Kirton, MD, MSc, University of Calgary*
16:30-17:15	Motor Control Basis of Use-Induced Therapy in CP	*Andrew Gordon, PhD, Columbia University*
17:15-17:30	GENERAL DISCUSSION	

18:00-20:00 Opening Reception
New Residence Hall Ballroom

Program

Sunday July 14, 2013

Registration 08:15–08:45
OPENING SESSION 08:45–09:00

Theme I
Cortical and Spinal Mechanisms of Motor Control
Chairs: Scott T. Grafton, UC Santa Barbara; C. J. Heckman, Northwestern University

8:50-9:00	Opening remarks	
9:00-9:35	Force Feedback and the Distribution of Limb Stiffness	*Richard Nichols, Georgia Institute of Technology*
9:35-10:10	An Integrated Neural Mechanism of Speed/ Accuracy Tradeoffs in Decision-Making and Action Execution	*Paul Cisek, University of Montreal*
10:10-10:45	Planning Actions in the Face of Many Options and Under Time Pressure	*Scott T. Grafton, University of California at Santa Barbara*
10:45-11:15	*Health Break*	
11:15-11:50	Reconfiguration of Motoneuron Electrical Properties for Different Motor Tasks	*C.J. Heckman, Northwestern University*
11:50-12:15	GENERAL DISCUSSION	
12:15–14:30	*LUNCH AND POSTER SESSION I*	

Theme II
Variability and Redundancy in Motor Control
Chairs: Mark Latash, Penn State University & Tamar Flash, Weizmann Institute of Science

14:30-15:05	Use of Uncontrolled Manifold Approach to Address Variability, Self-Motion and Motor Equivalence	*John P Scholz, University of Delaware*
15:05-15:40	The Dynamics of Inter-Trial Fluctuations Near Goal Equivalent Manifolds	*Joseph P Cusumano, Penn State University*
15:40-16:15	Variability and Noise in Motor Skill Acquisition	*Dagmar Sternad, Northeastern University*
16:15-16:35	*Health Break*	
16:35-17:10	Redundancy Resolution, Variability and Reference Frames in Arm and Gait Movements	*Tamar Flash, Weizmann Institute of Science*
17:10-17:30	GENERAL DISCUSSION	

Program

Monday July 15, 2013

Registration 08:15–08:45

Theme III

Equilibrium-Point Control and Perception –Action Coupling

Chairs: Anatol G. Feldman, University of Montreal & Michael T. Turvey, University of Connecticut

8:45-9:20	Control with Referent Configurations in a Hierarchical System	*Mark L Latash, Penn State University*
9:20-9:55	The Visual Control of Walking Over Rough Terrain	*Brett R Fajen, Rensselaer Polytechnic Institute, New York*
9:55-10:30	Action-Perception Coupling in Kinesthesia	*Anatol G Feldman, University of Montreal*
10:30-11:00	*Health Break*	
11:00-11-35	Efference Copy, Space Constancy and Saccadic Suppression	*Bruce Bridgeman, University of California, Santa Cruz*
11:35-12:05	GENERAL DISCUSSION	
12:00–14:30	*LUNCH AND POSTER SESSION II*	

Theme IV

Motor Control of Speech and Language

Chair: David Ostry, McGill University

14:30-15:05	Auditory Plasticity and Speech Motor Learning	*Douglas M Shiller, University of Montreal*
15:05-15:40	The Neural Substrates of Speech Motor Learning	*Frank H Guenther, Boston University*
15:40-16:15	Behavioral and Neural Mechanisms of Vocal Learning in Adult Birdsong	*Michael S Brainard, University of California at San Francisco*
16:15-16:35	*Health Break*	
16:35-17:10	Studies of Neural Mechanisms of Voice Control: Implications for Understanding Voice Deficits in Parkinson's Disease	*Charles R Larson, Northwestern University*
17:10-17:30	GENERAL DISCUSSION	
17:30-18:00	**BERNSTEIN AWARD**	
19:30-23:00	**BANQUET**	Le Windsor – Versailles Ballroom 1170 Peel St., Montreal *DJ: Nat Raider*

Program

Tuesday, July 16, 2013

Registration 08:15–08:45

Theme V

Motor Control and Recovery from Injury

Chairs: Mindy F. Levin, McGill University & John Rothwell, Institute of Neurology, University College London

8:45-9:20	Sub-Cortical Visuomotor Control of Human Limb Movement	*Brian L Day, Institute of Neurology University College London*
9:20-9:55	Adaptations to Neck/Shoulder Fatigue and Injury	*Julie N Côté , McGill University*
9:55-10:30	Enhancing Postural Stability and Adaptability in Multiple Sclerosis	*Richard E A van Emmerik, University of Massachusetts, Amherst*
10:30-10:50	*Health Break*	
10:50-11:25	Motor Adaptation after Brain Injury	*Mindy F Levin, McGill University*

12:00– 14:00 *LUNCH AND POSTER SESSION III*

Theme VI

Motor Control and the Performing Arts

Chairs: Robert Zatorre, McGill University & Roger Hobden, MD, University of Montreal

14:00-14:35	Loss of Motor Control in Highly Skilled Musicians: Musicians' Dystonia and its Implications for the Understanding of Motor Control	*Eckart Altenmüller, University of Music, Drama and Media, Hannover, Germany*
14:35-15:10	Motor Control in Action: Using Dance to Explore the Intricate Choreography Between Action Perception and Production in the Human Brain	*Emily S. Cross, Bangor University, UK*
15:10-15:45	Music and Movement: Neural Substrates of Auditory-Motor Interactions	*Robert J Zatorre, McGill University*
15:45-16:10	*Health Break*	
16:10-17:00	Dexterity and the Circus Arts in Training and Performance	*Samuel Tetreault, 7 Fingers Circus Company*
17:00-17:30	GENERAL DISCUSSION	

AWARDS AND CLOSING

Abstracts / Communications orales

The Potential for Stem Cell Therapies to Have an Impact on Perinatal Neurological Injury – the Hype, the Hope and the Reality

Crystal A Ruff, Stuart D Faulkner and Michael G Fehlings

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ABSTRACT

Cerebral Palsy (CP) – consisting of impairments in neuromotor development - is the most common developmental disability. With an estimated additional lifetime cost of 1.5 million dollars per individual, CP can be associated with significant financial, social and physical challenge. Stem cell therapy shows great promise for neurological repair, particularly in the case of perinatal brain injury, such as CP. Several types of stem cells – including neural precursor cells (NPCs), mesenchymal stem cells (MSCs) and other progenitors - have been investigated pre-clinically in neurological injury paradigms, with NPCs showing the ability to remyelinate lost or damaged white matter tracts. Furthermore, several groups have investigated cells from various species – such as human, murine and rat – in these experimental scenarios. While a handful of clinical trials exist for CP, there are currently only few exploring cell replacement strategies, with none yet exploring the effects of NPCs in CP trials. This presentation will investigate the etiology of CP, the types of stem cells currently being used in preclinical neurological injury scenarios and their expected function in human situations. Moreover, it will highlight work done in the Fehlings lab investigating remyelination of damaged white matter tracts and will further identify current clinical trials investigating the most common cell types for transplant in neurological disease, based on our recent review article in Developmental Medicine and Child Neurology (Ruff, Faulkner and Fehlings, 2013). If used in an appropriate and timely manner, stem cells show substantial potential for neuroregeneration; it is up to scientists, clinicians and families to work together to transform this potential into a future reality.

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Non-Invasive Brain Stimulation to Understand and Enhance Function in Hemiparetic CP

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ABSTRACT

Perinatal stroke is presented as the ideal human model of developmental neuroplasticity. The precise timing, mechanism, and location of specific perinatal stroke diseases are reviewed, providing common examples of well defined, focal perinatal brain injuries. Motor disability (hemiparetic cerebral palsy) is the primary adverse outcome and the focus of emerging models of how motor systems develop in health and following early injury. Combining basic science animal work with human applied technology (functional MRI, diffusion tensor imaging, transcranial magnetic stimulation) studies, a model of plastic motor development following perinatal stroke is presented. The ability of TMS to map the developing brain and understand how motor neurophysiology and plasticity evolve following focal perinatal injury will be outlined including the identification of potential central therapeutic targets. How such new understanding can be translated into therapeutic interventions will be highlighted by preliminary results and discussion of two ongoing clinical trials. Implications and future directions will be discussed.

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Motor Control Basis of Use-Induced Therapy in Cerebral Palsy

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ABSTRACT

Cerebral Palsy (CP) is a development disorder of movement and posture causing limitations in activity and deficits in motor skill as a result of non-progressive disturbances in the developing fetal or infant brain. CP is the most common cause of severe physical disability in childhood, with unilateral spastic cerebral palsy (USCP), characterized by motor impairments largely affecting one side of the body, being among the most common subtypes. USCP is generally the result of middle cerebral artery infarct, hemi-brain atrophy, periventricular white matter damage, brain malformation or posthemorrhagic porencephaly. The integrity of the motor cortex and corticospinal tract (CST) underlying dexterity is often compromised, with an aberrant organization of the motor system and the damaged side failing to establish normal connections. These abnormalities in connectivity of the motor system result in impaired development of dexterity. The extent of the damage, as well as resulting reorganization, are highly predictive of the severity hand impairments. The resulting impaired hand function is one of the most disabling symptoms of USCP. Consequently, children with USCP tend not to use the more affected extremity, which can lead to further deficits. Although motor learning is impaired, upper extremity performance in children with USCP may improve during development and following extensive practice. This implies that hand function is amenable to treatment.

Presently there are few evidence-based approaches to rehabilitation of these impairments. However, in the last decade, intensive motor learning approaches to rehabilitation have demonstrated considerable promise. Specifically, use-induced approaches, engaging the affected hand in functional and play activities such as constraint-induced movement therapy and bimanual training, have shown large improvements in hand function over short periods of time. Here we start by describing the pathophysiology of impaired hand function in these approaches. We then describe use-induced approaches to rehabilitation. The underlying ingredients and cortical plasticity in response to training are described. The results across studies suggest that although skilled hand use and motor learning may best drive plasticity in the motor cortex, the key ingredient to these approaches is the intensity and specificity of motor training. Recent work has demonstrated that these principles may be applied to lower extremity training.

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Force Feedback and the Distribution of Limb Stiffness

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ABSTRACT

Limb stiffness is a critical mechanical property that determines how the body interacts with the environment, and is regulated by both intrinsic and neural mechanisms. Intrinsic mechanisms include the mechanical properties of muscle, limb architecture and the inertial properties of limb segments. Neural mechanisms include feedback from muscle spindle receptors, Golgi tendon organs and other proprioceptors. In multi-segmented limbs, endpoint stiffness is a global property that determines how the limb as a whole will interact with the environment, while the stiffnesses of individual joints determine how perturbations are distributed throughout the limb. Cocontraction of adductor and abductor muscles of the ankle during stance, for example, ensures that the application of body weight to the limb will result in movement primarily along the long axis of the limb and stabilization of the ankle in the frontal plane. Monica Daley and Andrew Biewener have suggested that compliance is likely to be greatest in the distal limb where interaction with the ground takes place. We have recently investigated these issues and the task-dependence of proprioceptive feedback using reduced preparations that exhibit force production and/or stepping. The data suggest that the magnitude of stiffness measured at the endpoint of the limb and the manner in which stiffness is distributed in the proximo-distal direction are modulated in a task-dependent way by a proprioceptive network in the spinal cord that receives feedback from Golgi tendon organs. Under conditions of static force production, force feedback (FFB) is primarily intermuscular and inhibitory. During locomotion, inhibitory FFB is directed predominantly to the distal limb, and certain biarticular muscles exhibit autogenic excitation that is force-related. These modifications have the effect of focusing limb compliance on the distal limb, and increasing the mechanical coupling between knee and ankle joints. The evidence suggests that, during ramp walking, FFB is modulated and limb stiffness changes in an appropriate and corresponding manner. Alteration of a body position signal obtained by manipulating head and neck orientation results in reconfiguration of the central pattern generator for uphill and downhill locomotion. For the "uphill" condition, inhibitory force feedback is reduced, while for the "downhill" condition, inhibitory force feedback is enhanced, suggesting that limb stiffness is reduced. Indeed, under the "downhill" condition, direct measurements of limb stiffness show a significant decrease. Following spinal cord injury, FFB becomes redistributed in a manner consistent with the observed deficits in postural stability. After chronic or acute spinal hemisection, inhibitory force feedback is directed in a proximal direction in contrast to the distribution observed during the other locomotor tasks described above. The data indicate that the FFB network contributes in a major way to the distributed mechanical properties of the limb, providing an effective means to regulate the mechanical interface with the mechanical environment.

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An Integrated Neural Mechanism of Speed/Accuracy Tradeoffs in Decision-Making and Action Execution

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ABSTRACT

During natural behaviour, animals are faced with a variety of speed/accuracy trade-offs. Taking more time to decide usually results in a better choice, and moving more slowly increases the chance of success. However, for both decisions and actions, taking more time also reduces the total reward rate, motivating animals to find the right trade-off between speed and accuracy. While speed/accuracy tradeoffs in decisions and actions have traditionally been studied separately, I will show evidence that they may be controlled by a unified mechanism. Two monkeys were trained to make reach decisions in a free reaction-time choice task in which information about the correct target was provided gradually during each trial. Task timing parameters in a "fast" block of trials led to significant savings of time for early guesses, while the parameters in a "slow" block led to more modest savings. Both monkeys spontaneously adopted a policy in which their criterion of accuracy for making a choice decreased over time, and was lower in the fast than in the slow block. This is consistent with the hypothesis of a context-dependent "urgency signal" that grows over time to bring neural activity to a threshold for decision commitment. In agreement with that hypothesis, neural activity in dorsal premotor and primary motor cortex reflected the time-course of sensory information modulated by the putative urgency signal deduced from behaviour, and reached a consistent peak approximately 300ms prior to movement. At that moment, movement-related cells exhibited bursts of activity that correlated with the speed of the subsequent movement. Interestingly, the amplitude of that burst was stronger after long decisions, and consequently movements were faster. The relationship between movement duration and decision duration was context-dependent, as predicted by the urgency signal deduced from the monkeys' decision policy. This suggests that the same context-dependent urgency signal that influences the time taken to decide also influences movement-related neural activity. Remarkably, we found similar phenomena when we examined the speed of the unconstrained eye movements the monkeys made during the decision process. Again there was a gradual increase in velocity over time, mirroring our estimate of the context-dependent urgency signal. On the basis of this data, we suggest that a common arousal signal, possibly originating in the basal ganglia, modulates activity throughout the frontal cortex. It influences both the urgency to make a decision and the vigour of the movement that is chosen, thus maximizing what animals care about most: their total reward rate.

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Planning Actions in the Face of Many Options and Under Time Pressure

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ABSTRACT

When I see a light switch that must be turned on, do I specify multiple action plans to accomplish this goal? Recent work in non-human primates shows that during action selection, there can be neuronal activity, particularly in premotor regions, reflecting the parallel planning of movements by one effector to different motor goals. A combination of influences based on expected rewards, costs, experience and accumulating sensory information ultimately drive the selection process towards one of the competing actions. Here we ask if this process generalizes to situations where an action could be made with more than one possible effector. We also tested conditions were the need for parallel planning is amplified, by introducing a temporal deadline. Using both fMRI and EEG methods in humans, we examined a range of conditions where parallel planning might be present. We identified brain activity in frontal and parietal areas that is present in the network of the hemisphere contralateral to a performing hand, prior to movement onset. There is robust planning related activity in contralateral PMd, SMA, and PPC. If parallel planning occurs, then both hemispheres should be active when a target is presented, without information as to which hand will be used. However planning-related activity in each hemisphere was delayed if the responding hand was not specified. When the effector was specified, parietal EEG evoked responses occurred earlier and reflected individual differences in reaction times. This argues against a general feature of the nervous system to make parallel plans by different effectors to a common goal. We then tested if time pressure might increase the likelihood for detecting parallel planning processes. We created a simplified driving task, where participants must brake with one hand or accelerate with the other hand and in probe trials, make a decision at yellow traffic lights. Planning related activity was measured with fMRI and assessed with univariate as well as machine learning techniques. With the addition of time pressure created by the yellow light task, there is evidence for a general preparatory signal for bilateral planning areas. As the point of no return approached, multivoxel pattern analysis of single trial activity in posterior parietal cortex increasingly reflected the optimal behavioral choice. The findings highlight the fact that planning mechanisms are flexible, and planning of multiple actions by different effectors is highly dependent on the task context. Time pressure represents a critical factor that influences decision-making in basic motor tasks.

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Reconfiguration of Motoneuron Electrical Properties for Different Motor Tasks

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ABSTRACT

During the past 15 years, our studies as well as those of many colleagues have revealed ever greater complexity in the input-output properties of motoneurons. It is thus no longer tenable to consider motoneurons to be simple "threshold and fire" followers of motor commands. This complexity is puzzling though – why is such a wide range of motoneuron input-output states needed to implement motor behaviors? The guiding concept for this presentation is that this multiplicity of motoneuron states is in fact an adaptation to match the great diversity of the normal movement repertoire. We propose the following correspondences between motoneuron states and normal motor behaviors: (1) for posture, motoneurons may act as integrators to provide memory of brief inputs; (2) for a wide range of voluntary movements, motoneurons may act as variable gain amplifiers; and (3) for repetitive movements driven by central pattern generators, motoneurons may act as oscillators. Admittedly, these correspondences are overly simple, but they potentially provide an organizing hypothesis with clear predictions for experimental tests. The first two states are highly dependent on neuromodulatory input from the brainstem, mediated via actions of serotonin (5HT) and norepinephrine (NE), while the oscillatory state appears to depend primarily on glutamatergic NMDA inputs, adding a whole new dimension to motoneuron behavior. Preliminary studies of the integrative state (1), using a novel array electrode method that allows simultaneous recording of 10 to 20 motor units, suggest that motoneurons are capable of memory-like behavior. This memory however largely relies a population encoding mechanism. This work is largely in the decerebrate cat preparation. For the amplifier state (2), we have examined the effect of gain on precision of isometric force generation in human subjects. Drugs that affect 5HT levels in these subjects vary precision just as expected from the effect of 5HT on motoneuron gain: increased gain decreases precision and vice versa. For the oscillatory state (3), studies in animal preparations show that adult motoneurons become intrinsic oscillators in the presence of NMDA. We are presently testing the hypothesis that the spinal central pattern generations are the normal source of NMDA input to motoneurons. Overall, the concept that motoneuron electrical states are matched to different motor behaviors constitutes a novel way of looking at the organization of motor output and provides a functional basis for understanding the complexity of motoneuron input-output processing. The potential disruptions in these motoneuron states in spinal injury will be discussed.

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Use of Uncontrolled Manifold Approach to Address Variability, Self-Motion and Motor Equivalence

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ABSTRACT

In recent years, the importance of differentiating between variability of the human motor system that reflects noise versus providing an important window into how the CNS controls movements recently has been recognized, with the introduction of a number of approaches to address the issue. The uncontrolled manifold (UCM) approach, for example, is based on the UCM hypothesis, which states that the nervous system takes advantage of the inherent motor redundancy to provide for flexible coordination of a set of redundant effectors, or elemental variables, to ensure the stability of a task-relevant variable. The method allows decomposition of the variance of elemental variables across trials, cycles of performance or time into a component reflecting flexible coordination of those variables to achieve a relatively stable value of a specific task-relevant variable, versus variance that changes the state of that task variable. The contribution of each elemental variable to each variance component can also be identified to provide insight about contributions to that variance structure. By forming different hypotheses about variables most relevant for task success, the approach has been used to differentiate among their importance. More recently, the UCM approach has been used to address related issues such as motor equivalence and self-motion, independent of the variance of the motor elements. Motor equivalence has had different meanings in different contexts. Here, we refer to the ability to adopt different coordination states of elemental variables in the face of perturbations that help stabilize the value of a hypothetical task variable. For example, support surface perturbations lead to different joint configurations. The approach allows us to ask whether the configuration change is associated primarily with a change in the value of a task variable, e.g., the body's position in space, or whether more of the configuration change is directed to stabilize the task variable. Finally, while the UCM variance analysis provides clues about the nature of the control solution for a motor task, suggesting that a family of coordination solutions is used to stabilize a given task-relevant variable, it does not provide a clear indication of the extent to which flexible solutions are used. Self-motion is a concept from robotics indicating the extent to which there are changes in, for example, joint configurations that have no effect on the task under consideration. Self-motion is evaluated based on the derivatives of the elemental variables and their relationship to a particular task-relevant variable. For example, velocities of the joint configuration primarily must be directed toward the target of reaching. However, there also is a substantial amount of self-motion, a component of the joint configuration velocity that does not affect the hand's trajectory. These issues will be discussed in greater detail with illustrations of their application.

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The Dynamics of Inter-Trial Fluctuations near Goal Equivalent Manifolds

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ABSTRACT

The variability observed in repeated motor performance is a fundamental characteristic of perception-action systems. Here we describe investigations that consider fluctuations from the perspective of inter-trial task dynamics. Goal equivalent manifolds (GEMs), task manifolds defined using a minimal space of body-level variables needed to specify the outcome of an individual trial, together with simple optimal control ideas, are used to formulate dynamical models that serve as experimentally testable hypotheses on how inter-trial fluctuations are generated. Using these ideas one can precisely characterize the error-correcting control used by human subjects to regulate repeated movements. By applying our approach to a number of neuromechanically quite different tasks (gait, reaching, and generalized throwing), we demonstrate how dynamical methods can provide coordinate invariant measures of performance, and help unify our understanding of movement fluctuation dynamics across different levels of observation (e.g. local stability, fractal dynamics, task manifolds, feedback control). Our approach not only describes empirical variability data, but in principle can be used to make model-based predictions about the effect of parameters on fundamental features, such as stability properties and fluctuation statistics.

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Variability and Noise in Motor Skill Acquisition

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ABSTRACT

Learning motor skills such as throwing a ball, dancing, or drinking a cup of coffee are uniquely human and key to functional behavior. While much progress has been made to understand adaptation to external perturbations, acquisition of novel motor skills has received much less attention in current computational neuroscience. Our approach to skill acquisition is based on the concepts variability and stability. We start by analyzing how task dynamics constrains the solutions that successfully achieve the task goal. Explicit mathematical understanding of the task renders the redundancy, i.e. the manifold of solutions, and can reveal how the performer navigates in the task space to find the solution. Based on quantitative analysis of the solution manifold, analysis of variability sheds light on how learners explore different strategies, and tune their solutions to one that permits the remaining noise not to affect task success. By separating solution space from execution space, deterministic and stochastic components of performance can be parsed and analyzed separately. In different lines of work we showed how to apply this approach to sets of data as well as time series of data. Our results show that in healthy adults noise is the component that is least accessible to practice. These findings set the challenge to design interventions that target the reduction of noise.

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Redundancy Resolution, Variability and Reference Frames in Arm and Gait Movements

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ABSTRACT

In spite of kinematic redundancies of human limbs, stereotypical solutions to the inverse kinematics problem are chosen by the motor system in the performance of many motor tasks. Coordinate systems play a major role in resolving kinematic redundancies for both the upper and lower limbs. During locomotion it was found that the elevation angles of the leg segments covary on a plane (Lacquaniti et al. 1999) demonstrating a coordination pattern between the angular rotations of these segments. The elevation angles are defined with respect to gravity (extrinsic space). By contrast, no coordination pattern was found to emerge for the anatomical angles. A recent finding supports the existence of a preferred extrinsic frame of reference also for the upper limb. Using blind source separation methods to extract the sources of both task and joint-spaces, close similarity was found between those sources only when using the elevation angles representation. Using composition of such sources also simplifies the solution of the inverse kinematics problem, suggesting a functional advantage for this representation.

Additional studies dealing with the question of the existence of a smooth lower dimensional manifold in the configuration space to which movements are restricted will also be discussed. This is closely related to the notion of repeatability, i.e. every closed path in task space is performed by a closed path in configuration space. Finally results from the analysis of task level variability for drawing and locomotion trajectories along curved paths will be presented. Novel methods involving shape and time matching were developed to analyze position and velocity variability along 2D repetitions of the trajectories. The results indicated differences in position and velocity variability between different path segments depending on their curvature. Movement segmentation using variability and autocorrelation analysis will also be described.

These studies were carried jointly with A. Barilya, L. Omler, M. Giese, N. Arkind, M. Tyton and D. Bennequin.

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Control with Referent Configurations in a Hierarchical System

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ABSTRACT

We accept as an axiom that the neural control of natural voluntary movements is organized in a hierarchical way. At the top level of the hierarchy, a few salient, task-specific variables are reflected in a set of neural signals (possibly, subthreshold depolarization levels of neuronal pools). Further, as a result of a sequence of few-to-many mappings, these signals result in sets of tonic stretch reflex thresholds for the many muscles involved in the planned movement. This scheme naturally results in synergies stabilizing the values (time profiles) of task-specific, salient variables. In this context, "synergies" are defined as co-varied across repetitive trials adjustments within a redundant set of elemental variables that ensure stability of a performance variable to which they all contribute. Several consequences of this scheme have received experimental support in recent studies. First, the scheme implies a trade-off between indices of synergies at different hierarchical levels. Such trade-offs have been demonstrated for some variables during static prehensile and manipulation tasks, but not for all variables. Second, there is a possibility to modify synergies without changing performance and to modify performance without changing synergies. The former phenomena have been studied extensively as anticipatory synergy adjustments in both multi-digit prehensile and whole-body tasks. The latter phenomena have been demonstrated, in particular, during whole-body sway within a broad range of frequencies. Third, the scheme predicts adjustments in synergies when physiological properties of one (or a few) of the elements at a lower hierarchical level have been changed. Such adjustments of the synergy index have been documented in a series of studies of the effects of fatigue of one finger (one muscle group) on multi-finger (multi-muscle) synergies. Fourth, the scheme suggests that changes in performance with practice can involve contrasting effects on synergy indices depending on the design of the exercise. Recent studies have shown a counter-intuitive increase of variance in the space of commands to fingers (finger modes) with practice of accurate total force production with adjustments of stability properties of the task. This was accompanied by an increase in the synergy index such that variance of the total force dropped with practice. Recent studies of neurological patients with Parkinson's disease, olivo-ponto-cerebellar atrophy, and stroke have suggested an important role of subcortical circuits in the multi-element synergies. We would like to conclude that the idea of control with referent body configurations provides a rich framework for the analysis of natural movements, allows to make non-trivial predictions regarding multi-element synergies, and promises direct applications to the fields of motor disorders and motor rehabilitation.

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The Visual Control of Walking Over Rough Terrain

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ABSTRACT

When walking over flat, obstacle-free terrain, humans achieve remarkable energetic efficiency by exploiting the passive mechanical forces inherent to bipedal locomotion. The idea that energetic efficiency is achieved by exploiting passive forces has gained traction in the study of steady state walking. However, little is known about how these principles govern the control of walking over complex terrain containing obstacles and irregularly spaced safe footholds. Inspired by the dynamic walking model, we explored the hypothesis that when walking over rough terrain, vision is used to select footholds that allow the walker to approximate the efficiency of walking over flat terrain. We developed a novel experimental paradigm in which subjects walked over an array of randomly distributed virtual obstacles that were projected onto the floor by an LCD projector while their movements were recorded using a full-body motion capture system. Walking behavior was compared across different visibility conditions in which the virtual obstacles did not appear until they fell within a window of visibility centered around the moving subject. In a follow up experiment, subjects walked over a path of irregularly spaced virtual target footholds that became invisible at some point before subjects stepped on them. We found that when subjects could see at least two step lengths ahead, they were able to maintain forward progress and avoid obstacles as well as they could when vision was unconstrained. Likewise, when it was possible to see two step lengths ahead, the center of mass closely followed the trajectory of a passive inverted pendulum with the same initial conditions, implying an efficient exploitation of passive forces. We also found that the accuracy of stepping on a target was unaffected when the target became invisible at any point during the step to that target, but sharply declined when the target disappeared during the preceding step. Taken together, the findings suggest that humans use visual information about the upcoming terrain to choose footholds that allow them to exploit the passive mechanical forces that are inherent to bipedal walking and approximate the level of energetic efficiency that is achieved when walking over flat, obstacle-free terrain.

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Action-Perception Coupling in Kinesthesia

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ABSTRACT

According to previous studies, muscles become active in response to deviations from a threshold (referent) position of body segments. Intentional motor actions result from central shifts in the referent position that represents the origin point of the spatial frame of reference in which these actions are produced. We first tested the hypothesis that corticospinal pathways set and reset the referent position of body segments in a task-specific way without pre-determining movement kinematics and/or motor commands to muscles. Using TMS of the wrist motor cortex, we evaluated corticospinal influences at wrist positions established before and after voluntary motion. Such influences were also evaluated before and after involuntary motion elicited by sudden removal of a load (the unloading reflex). Although the tonic EMG levels at pre- and post-unloading wrist positions were substantially different, the corticospinal influences remained the same. These influences changed however when subjects voluntarily moved their wrist to another position. An additional analysis showed that corticospinal influences shifted the referent position at which wrist muscles were recruited when voluntary wrist motion was made but that they maintained the same referent position during unloading. Thus, central control strategies underlying the two types of motor actions are fundamentally different. The notion that the motor cortex may control motor actions by shifting spatial frames of reference for motor actions in a feed-forward way opens a new avenue in the understanding of how position sense (PS) is formed. It is suggested that somatosensory afferents inform the brain about the deviation (P) of body segments from the centrally set referent position, R. To identify the actual position (Q) of body segments and form the PS, the central and afferent signals are combined: Q=R+P. The PS rule was tested in three experiments in healthy subjects in the absence of vision. In Experiment 1, subjects made voluntary wrist movements to reproduce involuntary changes in position elicited by sudden unloading of wrist flexors. In Experiment 2, they reproduced elbow joint positions under different constant loads. In Experiment 3, subjects reported when they began to perceive elbow flexion elicited by biceps tendon vibration. In experiment 1, subjects successfully reproduced the involuntary changes in the wrist position. In Experiment 2, the error in the reproduction of the elbow position was independent of the load. In experiment 3, subjects were not aware of elbow flexion elicited by tendon vibration until the elbow excursion exceeded, on average, 10.3°, suggesting that the no-motion illusion resulted from equal and opposite vibration-induced changes in the central and afferent PS components. It is concluded that the R and P are additive components of PS and that, contrary to the conventional view, PS is independent of sense of effort or efference copy. The PS rule may also provide an explanation for kinesthetic illusions and the phantom limb phenomenon. This study advances our understanding of action-perception coupling in kinesthesia.

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Efference Copy, Space Constancy and Saccadic Suppression

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ABSTRACT

Space constancy is the perception that the visual world has a stable position despite the fact that all visual information arrives through retinas that are continually moving with respect to the world. Since the time of Helmholtz the dominant explanation for visual space constancy has been the efference copy or corollary discharge, a copy of the innervation to the eye muscles that sends an equal and opposite compensatory signal to the visual brain to compensate for the effects of eye movements. The goal was to achieve constancy of perceived visual direction and calibration of visually guided actions. Empirical work has shown, however, that the efference copy is too slow and has too low a gain to achieve either of these goals. This was demonstrated for instance by pressing on the outer canthus of one eye while the other is covered. This evokes a sustained perception of offset of the visual world even though the eye muscles compensate for the offset, maintaining fixation on the target. The perceived deviation is due to extraretinal signals (efference copy and oculomotor proprioception) that can be measured psychophysically by a nulling technique. At the same time the magnitude of the efference to the eye muscles can be measured by the deviation of the covered eye, using infrared recording. The result was that efference copy accounted for only about 5/8 of the required compensation. Proprioception, measured with an analogous method, added another ¼ of the compensation. The deficit in gain accounted quantitatively for some previously unexplained illusions of visual direction, but was still not enough to underlie space constancy. Newer alternatives to the efference copy theory maintain that visual position information is not compensated, but is destroyed during each saccadic eye movement and replaced by information from the new fixation. In a 'reference object' theory the visual system first identifies a saccadic goal target, usually but not always the object to be on the fovea after a saccadic eye movement. During the saccade information about the old image positions is destroyed, except for the reference object. If that object lands within a spatiotopic window after the period of saccadic suppression, the object is considered found and constancy of its position is assumed. Other objects in the new fixational view are localized relative to the reference object. It is only if the reference object is not found that efference copy, oculomotor proprioception and possibly other information sources are exploited to localize the new image, and space constancy often fails.

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Auditory Plasticity and Speech Motor Learning

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ABSTRACT

Numerous studies have shown the speech motor system to be highly responsive to changes in sensory input. Both auditory and somatosensory feedback, it seems, play a central role in the acquisition and maintenance of speech motor control. Consistent with these studies, models of speech production have highlighted the role of accurate, stable sensory representations that serve, in part, as the "goals" of speech movements. A separate (and considerable) body of work has demonstrated that auditory-sensory representations of speech sounds are not perfectly stable, but rather exhibit rapid adaptation to changing input conditions in both children and adults. The plasticity of auditory representations has important implications for the control of speech production, both in early speech motor development and in the sensory-based maintenance of speech accuracy that characterizes adult speech motor control. In this talk, I will describe a series of studies that explore the link between sensory and motor plasticity in the speech motor system. The studies combine the paradigm of sensorimotor adaptation (altering auditory feedback in real-time during speech production) with measures and manipulations of auditory-perceptual representations of speech sounds. The results reveal not only that auditory speech targets are flexible under conditions of altered auditory feedback, but that changes in sensory representations can have a direct impact on speech motor learning and performance.

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The Neural Substrates of Speech Motor Learning

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ABSTRACT

Speech production is a highly complex sensorimotor task involving tightly coordinated processing in the frontal, temporal, and parietal lobes of the cerebral cortex. For the past two decades, our laboratory has implemented, tested and refined a neurocomputational model, called the DIVA model, which characterizes these interactions. Babbling and imitation phases are used to train neural mappings between phonological, articulatory, auditory, and somatosensory maps in cerebral cortex. After learning, the model can produce syllables and words it has learned by generating movements of an articulatory synthesizer. The focus of this talk will be the model's learning process, in particular how auditory feedback is used to tune stored motor programs (feedforward commands) for speech sounds.

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Behavioral and Neural Mechanisms of Vocal Learning in Adult Birdsong

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ABSTRACT

Birdsong is a complex motor skill that is learned in a process that exhibits strong parallels to human speech acquisition. Adult birdsong in many species becomes 'crystallized' in that the learned song becomes highly stereotyped in its structure and normally changes little over time. However, a variety of experiments have used feedback perturbation in adult birds to demonstrate that crystallized adult song is malleable. In this talk I will focus on the effects of auditory feedback perturbation on the songs of adult finches. These experiments indicate that given appropriate instruction, adult birds can rapidly and adaptively modify the structure of their songs. Song modification can be elicited both by a process of externally guided reinforcement and by a process of self-driven error correction. These experiments demonstrate that the remarkable stability of adult song does not reflect an incapacity for adaptive vocal modification. Rather, they indicate that adult song remains fixed due to an ongoing process of feedback evaluation in which birds match their songs to a stable sensory target. Much of the neural circuitry that subserves song production and song plasticity has been elucidated. Previous work has identified a primary song motor pathway that is required throughout life for normal song production and that is the presumed locus of much of the plasticity that reflects modification of song. In addition, songbirds have a simplified but conserved cortical-basal ganglia circuit (the anterior forebrain pathway, AFP) that is specialized for song. I will describe work indicating that the AFP is not required for the production of well-learned adult song, but that disruptions of the AFP prevent a variety of forms of adult vocal plasticity, indicating a crucial role for this pathway in feedback-dependent adult vocal learning. Because the AFP is a simplified cortico-basal ganglia circuit that contributes to a single, quantifiable behavior, it may prove to be a useful system for further testing mechanism whereby such circuits contribute to learning more generally.

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Studies of Neural Mechanisms of Voice Control: Implications for Understanding Voice Deficits in Parkinson's Disease

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ABSTRACT

Building upon progress of recent years in the study of the role of auditory feedback in voice control, this presentation will focus on auditory-vocal control mechanisms in Parkinson's disease. Approximately 15 years ago, studies from various labs showed that sudden and unpredictable changes in the frequency or loudness of voice auditory feedback led to compensatory changes in voice fundamental frequency (F0) or amplitude output. Regardless of the direction of the stimuli, i.e., an increase or a decrease in pitch or loudness of the feedback, the responses generally opposed the stimuli. These responses were interpreted to mean that the vocal system functioned as a negative feedback control system that corrected for a mismatch between the desired F0 or loudness and the actual feedback level.

Individuals with Parkinson's disease exhibit voice deficits characterized as too quiet and monotone. At the same time, the patients themselves insist that they are talking loud enough. We recently tested a group of individuals with Parkinson's disease and age/sex matched control subjects in the voice auditory perturbation paradigm. The group of Parkinson's disease showed larger amplitude vocal responses to both pitch- and loudness-shifted voice feedback compared with healthy control subjects. Data from this study suggest that the characteristic soft, quiet monotone voice frequently observed in Parkinson's disease may be related to their exaggerated response to unexpected shifts in voice auditory feedback. The details of the underlying neural mechanisms are unknown but could be related to abnormal processing of sensory feedback or sensory-motor integration.

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Sub-Cortical Visuomotor Control of Human Limb Movement

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ABSTRACT

It is generally accepted that cortical networks are responsible for controlling limb movements from visual information. However, there is a growing body of evidence that sub-cortical visuomotor control may also have an important role to play, even in man. Such a process could, for example, involve the superior colliculus which i) receives direct visual input, ii) has limb movement-related firing patterns, iii) evokes limb movements when stimulated, and iv) is active during human reaching movements. Behavioural evidence for sub-cortical visuomotor control in man comes from studies on the very fast responses that occur when a target unexpectedly jumps to a new location during either an upper-limb reaching movement or a lower-limb stepping movement. In both cases the target-jump evokes a correction in the movement trajectory at a surprisingly short latency of 120-160 ms. These very fast visuomotor reactions have a number of properties that are compatible with sub-cortical control: 1) they are not abolished by effort of will - when subjects are instructed to move their arm in the opposite direction to a target if it jumps during a reach, the arm continues to move involuntarily towards the new target location with the same short latency; 2) they can be made even faster by a startling auditory stimulus - when stepping onto floor-mounted target, if a non-informative loud sound is delivered either simultaneously with a target jump or during non-jumping control trials, the visuomotor response to the target jump is shortened by ~20 ms; 3) they do not obey Hick's law – as for ocular saccades, but unlike most other voluntary movements, the reaction-time remains constant regardless of the number of possible movement choices. To test directly the sub-cortical hypothesis, experiments were performed on a subject with agenesis of the corpus callosum. Because this condition precludes direct communication between left and right cerebral cortices, a purely cortical visuomotor process would be expected to produce longer-latency responses to a target that appears in the visual hemifield contralateral to the responding limb (crossed) compared with the ipsilateral hemifield (uncrossed). This prediction was confirmed for a reaction task involving arbitrary associations between limb movement and visual cue, which resulted in a consistent crossed-uncrossed latency difference of ~36 ms. Importantly, however, a crossed-uncrossed latency difference was not present for the short-latency reach adjustments evoked by the same visual cues. Together, these data support the idea of a fast-acting sub-cortical visuomotor network and raises the possibility of an intact pathway being available for controlling visually-guided action in the event of cortical damage.

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Adaptations to Neck/Shoulder Fatigue and Injury

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ABSTRACT

The development of neck/shoulder injuries, especially those related to work, oftentimes follows a long-term course that is thought to be related to the accumulation of fatigue and insufficient recovery following long-duration, low-force efforts. Increasingly sedentary lifestyles and work relying more and more on the use of computers are thought to only aggravate this costly public health issue. Previous studies have identified the Cinderella muscle fibres as a likely weak link in the mechanisms of development of such injuries; however, motor control mechanisms associated with overload of these fibres as injury develops remain poorly understood. We have recently described task-specific posture and movement adaptation patterns following repetitive motion-induced fatigue in healthy individuals and in people diagnosed with neck/shoulder disorders, highlighting similarities as well as differences between groups. Here, we present results from recent experimental work using repeated measures designs to study whole-body sensory and proprioceptive mechanisms, motor variability and inter-muscle patterns during repetitive work-like tasks producing upper limb fatigue. Taken together, the findings of these studies support the notion that access to a reduced motor repertoire may be associated with a higher likelihood, and even a predisposition to develop musculoskeletal disorders. Moreover, recent studies comparing motor patterns of men and women will be presented as part of a general model of the development of work-related neck/shoulder disorders, and specifically as part of a model to help explain the higher prevalence and chronicity of neck/shoulder disorders amongst women. Results of these studies are coherent with our previous findings in that these data suggest that women may benefit from a smaller motor repertoire with respect to work task demands, which could explain their higher likelihood of developing neck/shoulder disorders. However, psychosocial and organizational characteristics may also need to be taken into account as part of this injury model, in accordance with the sex- and gender-sensitive models of disease production. Lastly, we present preliminary findings from intervention studies focusing on modification of work posture and measurement of biomechanical as well as vascular patterns in association with work time and symptom development. Results of these studies could be used as a basis to prescribe individual- and gender-specific work adaptations to prevent the development of neck/shoulder disorders, based on the identification and use of appropriate injury exposure measurement tools and approaches.

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Enhancing Postural Stability and Adaptability in Multiple Sclerosis

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ABSTRACT

Multiple sclerosis (MS) is a chronic demyelinating disease of the central nervous system and is the most common neurological disease in 20-50 year old individuals. People living with MS consistently rate balance impairment as one of the greatest negative impacts on their quality of life, yet our understanding of the cause of instability in these individuals remains limited. Our research aims to understand the sensorimotor contributions to balance dysfunction and difficulty with walking in people with MS, with specific attention paid to how fatigue, muscle weakness, and sensory loss interact to limit physical function and mobility. In this paper we will relate aspects of somatosensory loss and symptomatic fatigue to balance function, and will provide new insights in our understanding of the mechanisms of balance and gait dysfunction in MS through the use of novel analytical methods and experimental paradigms. We will first review existing methods and paradigms to assess postural and gait stability in research on MS. Next, we will introduce novel measures to assess the stability and adaptability of posture and gait in people with MS that are based on nonlinear and complex systems methods. These novel methods include (1) boundary-relevant measures of postural stability and control (postural 'time-to-contact'), and (2) entropy measures for assessing postural and gait adaptability. These novel methods allow us to differentiate between postural and gait variability caused by dysfunction and variability that provides adaptability with which to respond to postural challenges. Finally, we will discuss how these methods and paradigms may help in developing innovative treatments for balance and gait dysfunction in people with MS.

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Motor Adaptation after Brain Injury

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ABSTRACT

In the healthy nervous system, the capacity for kinematic redundancy allows the system to find many different solutions or combinations of joint rotations to perform any given task, leading to a desirable amount of flexibility. After damage to the central nervous system such as brain injury or stroke, sensorimotor activity is disrupted and individuals are less able to accomplish functional tasks using pre-morbid muscle activation and/or kinematic patterns. One reason for this is a decrease in redundancy, limiting the number of ways a movement can be performed. Because of this limitation, the system seeks to find alternative solutions to movement through motor compensations. Changes in motor patterns used to accomplish the same task may be considered to be adaptive, if they lead to positive functional outcomes but they remain compensatory when they represent deviations from motor patterns observed in healthy individuals. Compensations are considered to be undesirable because they may interfere with recovery of typical movement patterns and may lead to 'learned non-use' or 'bad-use'. We will describe compensations used for motor actions of the upper limb in patients with stroke such as excessive trunk displacement for reaching towards targets placed within arm's reach, trunk and scapular displacement during arm swinging, excessive shoulder abduction during attempts to reach sagitally and use of the trunk to orient the hand for grasping. We will then describe how compensatory actions may be explained by limitations in the regulation of motoneuronal thresholds at the single and double-joint level. The threshold control theory of motor control describes how central regulation of reflexes, including the stretch reflex, results in different motor actions, in particular, muscle relaxation, motion, and isometric torque production in single- or multi-joint systems. Research in animals and in healthy subjects suggests that the tonic stretch reflex threshold (SRT) may be altered by descending systems mediating both direct and indirect influences on motoneurons. The SRT also depends on the velocity of change in the muscle length. How deficits in agonist-antagonist muscle activation in the single-joint elbow system in patients with spastic hemiparesis are related to limitations in the range of regulation of the SRTs and motor compensations will be discussed. The discussion will extend to deficits in multi-joint control in subjects with spasticity and to the ability of a measure of SRT to discriminate between different types of hypertonic disorders. Limitations in the regulation of SRTs result in a subdivision of all-possible elbow or shoulder-elbow arm configurations into different spatial zones in which spasticity, weakness, the ability to make intentional movements by producing a reciprocal activation of agonist and antagonist muscles, or only coactivation of antagonist muscles can occur. The implications for motor learning and recovery will be discussed.

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Loss of Motor Control in Highly Skilled Musicians: Musicians' Dystonia and Its Implications for the Understanding of Motor Control

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ABSTRACT

Sensory-motor skills of musicians have some specific qualities: learning begins at an early age in a playful atmosphere. Routines for stereotyped movements are rehearsed for extended periods of time with gradually increasing degrees of complexity. Via auditory feedback, the motor performance is extremely controllable by both, performer and audience. All movements are strongly linked to emotions, – pleasure or anxiety - , processed by the limbic system. These specific circumstances seem to play an important role for plastic adaptation at several levels of the central nervous system.

There is a dark side to the increasing specialisation and prolonged training of modern musicians, namely loss of control and degradation of skilled hand movements, a disorder referred to as musicians' cramp or focal dystonia. The first historical record, from 1830, appeared in the diaries of the ambitious pianist and composer Robert Schumann. As was probably the case for Schumann, prolonged practice and pain syndromes due to overuse can precipitate dystonia, which is developed by about 1% of professional musicians and frequently ends their career. Neuroimaging studies point to dysfunctional (or maladaptive) neuroplasticity as its cause.

In this paper, we will present new data on dysfunctional plasticity in musicians suffering from dystonia and demonstrate how subtle deficits in extensively trained fine motor skills can be reliably assessed using advanced MoCap procedures and specific data processing. Risk factors for developing focal dystonia will be discussed and new data concerning the task-specificity of the disorder will be presented. Furthermore, the complex phenomenology of musician's dystonia will be addressed by focusing on the "sensory trick", an improvement of dysfunctional movements in some patients when altering either auditory or tactile feedback. We will discuss the role of multisensory integration, feed-forward prediction and internal modeling. Finally, we will present a model accounting for our findings concerning the musicians' multi-sensory-motor systems and its pathology and discuss its implication for our understanding of action planning and motor control in general.

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Motor Control in Action: Using Dance to Explore the Intricate Choreography Between Action Perception and Production in the Human Brain

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ABSTRACT

When experienced dancers watch other dancers perform, they understand and appreciate the movement in a fundamentally different manner than non-dancers. Is this simply a matter of dancers paying more attention and having greater interest in watching dance, or do quantifiable differences exist within the brains of skilled dancers compared to non-dancers that can be traced back to greater physical experience and expertise? Previous neurophysiological research offers some insight into this question through the discovery of specialized cells in the monkey brain that are active in a similar manner when monkeys perform or observe the same movement. This discovery of so-called 'mirror neurons' established the idea of a close correspondence between action perception and production. Since this discovery, myriad studies have focused on the relationship between action production and perception in the human brain by studying the execution and observation of simple finger or hand movements. Over the past several years, my colleagues and I have developed a research program to extend this work by addressing questions of full-body action resonance using dancers as subjects and dance movements as stimuli. In this presentation, I will discuss findings from several studies from our laboratory that use dance to explore how individual experience shapes the links between watching and performing actions. This research capitalizes upon recent advances in neuroscientific methods to advance our understanding of not only the cerebral phenomena associated with complex action learning and observation, but also the neural underpinnings of aesthetic appreciation when watching dance. The results of this work are starting to inform and mutually benefit both the scientific and artistic communities.

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Music and Movement: Neural Substrates of Auditory-Motor Interactions

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ABSTRACT

Auditory and motor information appear to be preferentially coupled. This phenomenon has been explored in speech, but is also particularly evident in music. Motor entrainment occurs readily to rhythmic music, even in infants, and motor synchronization to temporally organized stimuli is more accurate for auditory than visual stimuli. These observations suggest that there might be preferential interactions between the auditory cortex and the motor systems of the brain. To test this hypothesis, we have developed behavioral tasks that allow us to examine rhythm synchronization performance as a function of musically relevant temporal complexity (i.e., metrical structure) in order to identify the temporal features of auditory stimuli that facilitate motor response. Using these tasks, we have conducted a series of functional magnetic resonance imaging studies to elucidate the neural basis for interactions between the auditory and motor systems in the context of musical rhythm perception and production. Our results show that higher-order aspects of the temporal organization of auditory rhythmic stimuli exert a strong influence on motor performance, and that motor regions of the brain are sensitive to the temporal organization of auditory stimuli. Specifically, we have observed significant coupling between neural activity in posterior auditory cortices and dorsal premotor cortices as a function of metrical organization. In addition, we can observe neural responses to rhythmically organized auditory stimuli in premotor cortical areas, as well as cerebellum, even in the absence of movement, or of the intent to move. More recently we have shown that perception and production of the higher-order musical beat involve interactions between auditory, ventrolateral prefrontal and striatal systems. Based on these findings, we propose a model for auditory–motor interactions in rhythm perception and production that involve the posterior superior temporal gyrus, and the ventral and dorsal premotor cortex, as well as ventrolateral and dorsolateral prefrontal cortex. These findings help to explain the significant influence of music on movement, and have relevance for applications to clinical domains as well.

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Poster Session I
Communications par affiche I

*** abstracts can be found at www.mcgill.ca/spot/pmcix/abstracts**

Theme I: Cortical and Spinal Mechanisms of Motor Control

Poster board numbers are indicated in left column. Authors will present posters on ***Sunday July 14 from 12:15 to 14:30.***

No.	AUTHORS	TITLE
7	**CL Massie, P Narayanan, SS Kantak, LM Jones-Lush, TN Judkins, O Levine, I Jonkers, S Swinnen, GF Wittenberg** USA	**Effects of motor cortical stimulation during planar and 3D reaching movements**
12	**DT Corp, G Tooley, AJ Pearce** AUSTRALIA	**The maintenance of attention during two concurrent motor tasks: Preliminary findings using transcranial magnetic stimulation**
13	**S Madhavan, A Sriraman, T Oishi** USA	**Timing dependant effects of tDCS on ankle motor skill acquisition**
16	**MJ Asmussen, CM Zapallow, MJ Jacobs, KGH Lee, P Tsang, AJ Nelson** CANADA	**Non-selective change in short-latency afferent inhibition during movement preparation**
22	**DT Corp, G Tooley, AJ Pearce** AUSTRALIA	**Corticomotor responses during dual task performance: A systematic review of the literature from 1995-2012**
23	**A Tryfon, N Foster, T Ouimet, K Doyle-Thomas, E Anagnostou, A Evans, L Zwaigenbaum, K Hyde & NeuroDevNet ASD Imaging Group** CANADA	**Brain anatomical correlates of auditory-motor synchronization in children with autism spectrum disorder**
24	**M Berchicci, F Menotti, A Macaluso, F Di Russo** ITALY	**The neurophysiology of central and peripheral fatigue during sub-maximal lower limb isometric contractions**
34	**DE Adamo, AM Daugherty, N Raz** USA	**Increased iron content in the basal ganglia is associated with grasp-force matching**
41	**AJ Pearce, HGK Drury, PC Gardiner, GA Tooley** AUSTRALIA	**Can you feel it? Sensation recognition and corticospinal excitability responses to low-level transcranial direct current stimulation**
43	**KM Trewartha, A Garcia, DM Wolpert, JR Flanagan** CANADA	**Age-related changes in motor learning due to altered adaptive processes in the elderly**
71	**CDC Altermann, AS Martins, FP Carpes, PB Mello-Carpes** BRAZIL	**Motor learning in young and elderly: influence of mental practice, observation of movement and cognition**
81	**DR Toledo, JA Barela, AF Kohn** BRAZIL	**Age-related differences in beta electroencephalographic changes during threshold of perception of ankle passive motion assessment**
83	**J DeSimone, J Weiler, M Heath** CANADA	**Directionally correct antisaccades reduce the effectiveness and efficiency of stimulus-driven saccade networks**
88	**S Davarpanah Jazi, J Bryce, M Heath** CANADA	**Goal-directed grasping: Receptor density influences the fidelity of haptic signals for perceptual and motor processing**
90	**J Weiler, M Heath** CANADA	**Archetypal and cued antisaccades yield fundamentally different oculomotor behaviours**
104	**JE Deffeyes, B Touvykine, B Khoshkrood Mansoori, S Quessy, N Dancause** CANADA	**Paired pulse electrophysiological investigation of corticocortical interactions of the rostral and caudal forelimb motor areas in the rat**
107	**N Ilmane, S Sangani, AG Feldman** CANADA	**Corticospinal control strategies underlying voluntary and involuntary wrist movements**
108	**J Polechoński, G Juras, K Słomka, J Błaszczyk** POLAND	**It is possible to use static posturography in the assessment of sensorimotor gating**
111	**M Piecha, G Juras, P Król, A Polak, G Sobota, B Bacik** POLAND	**The effect of short- and long-term whole body vibration on postural stability**

Poster board numbers indicated in left column. Authors will present posters on ***Sunday July 14 from 12:15 to 14:30.***

No.	AUTHORS	TITLE
113	**P Lindberg, K Sanchez, S Poiraudeau, A Feydy, MA Maier** FRANCE	**Correlation of impaired hand and foot force control and cervical spinal cord structure in early stages of cervical spondylotic myelopathy**
124	**Y Tanaka** JAPAN	**Modulation of EMG activity and spinal reflex during a balancing task using lower limb under psychological pressure**
133	**S-W Park, J Ebert, D Sternad** USA	**Learning and retention of an asymmetric bimanual task**
135	**TN Welsh, SM Pacione, HF Neyedli** CANADA	**Trajectory deviations in individual and social aiming tasks**
141	**M Teremetz, C Malherbe, MO Krebs, C Oppenheim, P Lindberg, I Amado** FRANCE	**Deficient cortical activity during motor inhibition in schizophrenia**
144	**R Huys, L Spiecer, M Bonnard, VK Jirsa** FRANCE	**Movement and brain dynamics at various scales**
154	**H McGregor, PL Gribble** CANADA	**Brain networks underlying motor learning by observing assessed using resting-state fMRI**
156	**J Bouffard, LJ Bouyer, JS Roy, C Mercier** CANADA	**Acquisition and retention of force field adaptation during human gait**
157	**M Lamothe, M Gagné, JS Roy, L Bouyer, C Mercier** CANADA	**Acquisition and retention of force field adaptation during human reaching**
162	**P Katona, J Laczko** HUNGARY	**Influence of cycling cadence and crank resistance on range of knee angles in which flexor and extensor muscles co-activate during cycling**
164	**D Andrew, H Haavik, P Yielder, B Murphy** CANADA	**The effect of a thumb motor training task on median nerve sensory processing**
165	**E Dancey, J Srbely, B Murphy, P Yielder** CANADA	**The effect of experimental pain on motor training performance and sensorimotor integration**
169	**J Baarbé, J Daligadu, H Behbahani, P Yielder, B Murphy** CANADA	**The effects of motor learning on the cerebellum and motor cortex**
171	**L Holland, J Baarbé, B Murphy, P Yielder** CANADA	**Asymmetry in inhibition and facilitation between dominant and non-dominant hemispheres in right-handed individuals**
177	**A Pham, Z Miranda, D Barthélemy** CANADA	**Postural reactions to tilts of the base of support: contribution of foot afferents**
179	**A Hernandez, N Ilmane, T Brohman, A Mullick, MF Levin, AG Feldman** CANADA	**Patterns of residual corticospinal influences in post-stroke spasticity**
180	**DK Cheung, H Carnahan, G Mochizuki** CANADA	**Dissociating central set and motor preparation using transcranial magnetic stimulation**
187	**T Krasovsky, A Lamontagne, AG Feldman, MF Levin** CANADA	**Faster is not more stable: speed effects on interlimb coordination and gait stability in young and older adults**
189	**DK Sumanapala, CJ Steele, VB Penhune** CANADA	Differential learning of sequence accuracy and synchronization across six days of practice
190	**D Barthélemy, A Valois, D Pinotti, JB Nielsen, V Marchand-Pauvert** CANADA	**Vestibular modulation of a propriospinal-like reflex during gait**

Poster board numbers indicated in left column. Authors will present posters on ***Sunday July 14 from 12:15 to 14:30.***

No.	AUTHORS	TITLE
191	**A Hamaoui, L Laviolette, A Hudson, MC Nierat, T Similowski** FRANCE	**Effects of unilateral and bilateral contractions of the diaphragm on posture**
192	**PA Mathieu, N Nejat, J Florestal, D Filion, M Bertrand** CANADA	**Investigation on the control of the biceps brachii**

Theme II: Variability and Redundancy in Motor Control

Poster board numbers are indicated in left column. Authors will present posters on ***Sunday July 14 from 12:15 to 14:30.***

No.	AUTHORS	TITLE
11	**MJ Asmussen, EP Przysucha, N Dounskaia** CANADA	**The dominant role of arm's dynamics in the solution of kinematic redundancy during catching provides insights into Developmental Coordination Disorder (DCD)**
17	**YH Wu, N Pazin, VM Zatsiorsky, ML Latash** USA	**Practice effects on multi-finger synergies in accurate force production tasks with graded instability**
20	**FP Carpes, M de Britto, L Ueda, M Kunzler, L Lopes** BRAZIL	**Lower leg skin stimulation as a tool for improving postural control in the elderly**
25	**AD Nordin, JS Dufek** USA	**Examining lower extremity range of motion and movement variability changes due to focus of attention during landing**
28	**SL Gorniak** USA	**Inferring task complexity: Moving beyond Fitts' Law**
31	**S Togo, T Kagawa, Y Uno** JAPAN	**UCM reference feedback control for joint coordination**
42	**M Casteran, P Hilt, T Pozzo, E Thomas** FRANCE	**An analysis of the centre of mass trajectories during a whole body pointing movement**
44	**S Ambike, F Paclet, M Latash, V Zatsiorsky** USA	**Grip force modulation with wrist flexion and extension**
51	**KD Runnalls, BKV Maraj** NEW ZEALAND	**The effect of target geometry on foot placement variability during adaptive locomotion in a novel stepping stone paradigm**
53	**SL Barton, B Fajen** USA	**Learning to exploit motor redundancy**
55	**M Wünnemann** GERMANY	**Direction-specific learning in stabilometer balance tasks**
62	**E Nowak, B Grimme, H Reimann, G Schöner** GERMANY	**Direction dependent coarticulation in joint angles during sequential arm movements**
64	**F Paclet, S Ambike, ML Latash, VM Zatsiorsky** USA	**Interactions between grip force and hand force produced by wrist flexion**
65	**H Enders, C Maurer, J Baltich, BM Nigg** CANADA	**Structured variability in muscle activation patterns during cycling at different muscular demands**
67	**P Lamb** GERMANY	**Coordination stability in the golf swing with changing task constraints**
89	**MM Mazich, BE Studenka, KM Newell** USA	**Visual-motor tracking depends on the temporal location of visual information about properties of the target path and the target path regularity**
105	**TH Kakebeeke, J Caflisch, OG Jenni** SWITZERLAND	**The need of standardized assessment of motor performance in preschool children**
118	**P Arpinar-Avsar, J Park, VM Zatsiorsky, ML Latash** TURKEY	**Effects of muscle vibration on multi-finger interaction and coordination**
122	**MJ Kim, JK Shim, S Kim** SOUTH KOREA	**Developmental changes of whole-body synergy in squat-to-stand movement**
130	**H Katsumata** JAPAN	**Timing of executing a whole-body interceptive movement, consisting of multiple movement components**

Poster board numbers are indicated in left column. Authors will present posters on ***Sunday July 14 from 12:15- 14:30***

No.	AUTHORS	TITLE
136	**C Hasson, Mabe, Z Zhang, D Sternad** USA	**Error amplification improves performance by reducing neuromotor noise**
137	**H Cantú, K Emery, JN Côté** CANADA	**Effects of additional weight on posture-movement adaptations to repetitive arm motion-induced fatigue**
140	**B Nasseroleslami, CJ Hasson, D Sternad** USA	**Strategies in rhythmic object manipulation: predictability or chaos**
145	**R Huys, D Perdikis, VK Jirsa** FRANCE	**Functional architectures using structured flows on manifolds**
148	**C Hansen, T Zhang, N Rezzoug, P Gorce, B Isableu, G Venture** FRANCE	**Differentiation of pointing movements using a feature value method**
149	**CA Vernooij, RF Reynolds, M Lakie** UNITED KINGDOM	**Physiological finger tremor size reflects altered mechanical properties of muscle resulting from changes in neural control**
161	**FG Martínez, RG da Rosa, HB Oliveira, CC Ely, RL Chaves, LAP Tartaruga** BRAZIL	**Influence of load and speed on inter-segmental coordination and stride-to-stride variability of gradient walking**
163	**ME Huber, D Sternad** USA	**Learning to exploit dynamic stability in a motor task**
167	**N Korsantia, M Huber, D Sternad** USA	**Persistent decrease in neuromotor noise by manipulating error tolerance**
173	**A Amado, C Palmer, R Van Emmerik** USA	**Postural task constraints and bimanual rhythmic coordination**
176	**S Kaichida, Y Hashizume, S Torii, Y Iida, J Nishii** JAPAN	**Development of leg joint synergy during walking with growth**
194	**TM Sibindi, M Ginzburg, O Donchin, MA Frens** THE NETHERLANDS	**Characterizing the effects of sum of sine stimuli on the linearity and non-linearities of the compensatory eye movement system**

Poster Session II
Communications par affiche II

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Theme III: Equilibrium-point control and perception-action coupling

Poster board numbers indicated in left column. Authors will present posters on ***Monday July 15 from 12:00 to 14:30.***

No.	AUTHORS	TITLE
6	**ME Scheicher, LCS Fonseca, I Feitosa** BRAZIL	**Effect of additional sensory information on mobility of fallers and non-fallers elderly**
9	**A Kennedy, A Guevel, H Sveistrup** FRANCE	**Impact of forearm fatigue on the postural response to an externally initiated, predictable perturbation**
10	**YJ Lee, A Aruin** USA	**Stance-related changes in postural control during hand pushing**
18	**SA Aguiar, FV Narciso, A Carvalho, MT Mello, S Tufi, JA Barela** BRAZIL	**Effects of sleep deprivation on sensorimotor coupling adaptation in night shift workers**
27	**L Dumont, I Broer, J Ghaziri, H Théoret, M Beauregard** CANADA	**The construction of subjective judgments about one's own movements: a transcranial magnetic stimulation study**
29	**R Sleimen-Malkoun, JJ Temprado** FRANCE	**Age-related changes in the dynamics of movement patterns: insights from discrete Fitts' task**
47	**S Hanneton, EO Boyer, V Forma** FRANCE	**Influence of an error-related auditory feedback on the adaptation to a visuo-manual perturbation**
58	**L Fautrelle, D Mareschal, R French, E Thomas** FRANCE	**Interval timing judgements altered by motor activity**
70	**TR Bonfim, DC Botelhos** BRAZIL	**Effect of sensorimotor training using additional sensory information on balance**
72	**J Blinch, IM Franks, R Chua** CANADA	**Eliminating the preparation cost for bimanual asymmetric movements**
79	**ST Pedão, JA Barela, PB de Freitas** BRAZIL	**Visuomotor processing and grip and load force coordination in dyslexic children.**
80	**TR Bonfim, TC Alvisi, GC Abreu, LR Cordeiro, RV Conti, JMR Bacha** BRAZIL	**Age-related differences on static balance, berg balance scale and timed up and go test**
86	**C Teixeira-Arroyo, FA Barbieri, R Vitório, LTB Gobbi** BRAZIL	**Spatiotemporal parameters of gait during stair negotiation in people with Parkinson's disease: Relationship to disease severity, use of the handrail and difficulty self-perception to go up and down the stair**
87	**JS Rocha, SMA João, FA Hazime, RH Hasue** BRAZIL	**Postural control in children with visual impairment in the age groups 5 – 11 years– partial analysis**
98	**T Brohman, N Ilmane, A Hernandez, AG Feldman** CANADA	**Corticospinal control of elbow movement**
103	**BJ Martin, BC Lee, KH Sienko** USA	**Proprioceptive properties of torso cutaneous information and postural control**
106	**N Ilmane, S Sangani, H Raptis, N Esmailzadeh, AG Feldman** CANADA	**Action-perception coupling in kinesthesia: a new approach**
117	**C Hansen, N Rezzoug, P Gorce, B Isableu** FRANCE	**Rotation axes changes during a throwing task**

Poster board numbers indicated in left column. Authors will present posters on ***Monday July 15 from 12:00 to 14:30.***

No.	AUTHORS	TITLE
150	**N Ilmane, D Barthélemy, AG Feldman, C Duclos** CANADA	**Gait initiation to a moving surface: modulation of anticipatory postural adjustment.**
151	**K Koh, HJ Kwon, JK Shim** USA	**Influence of intra-auditory sensory integration in isometric finger force production**
155	**JM Prado-Rico, M Duarte** BRAZIL	**Postural asymmetry and muscular demands in young and elderly adults during quiet and relaxed standing**
170	**LD Rosado, MA Busa, J Lim, D Simon, REA Van Emmerik, CJ Palmer** USA	**The effects of soldier load on action perception and posture dependent target engagement timing**
185	**PS Archambault, JY Liu** CANADA	**Arm movements against an elastic load with an unexpected change in stiffness**
195	**M Lakie, CJ Osler, RF Reynolds, JPR Scott, AT Stevenson, CA Vernooij** UNITED KINGDOM	**Increased gravitational force reveals the mechanical nature of physiological tremor**
198	**RF Reynolds, PW Watts, CJ Osler** UNITED KINGDOM	**Mechanisms of interpersonal sway synchrony**
199	**CJ Osler, RF Reynolds** UNITED KINGDOM	**Age-related changes in the vestibular control of balance**

Theme IV: Motor Control of Speech and Language

Poster board numbers indicated in left column. Authors will present posters on ***Monday July 15 from 12:00 to 14:30.***

No.	AUTHORS	TITLE
26	**A Acher, M Sato, L Lamalle, C Vilain, A Attye, A Krainik, G Bettega, CA Righini, B Carlot, M Brix, P Perrier** FRANCE	**Neural correlates of speech recovery after intra-oral surgery**
32	**M Sato, C Vilain, L Lamalle, K Grabski** FRANCE	**Sensory-motor adaptive changes of orofacial and speech actions without overt motor behavior: an fMRI-adaptation**
37	**P Tremblay, C Routhier, M Mercure-Bilodeau, M Sato** CANADA	**Speech motor control in aging: effects of sequencing and articulatory complexity**
63	**B Kleber, AG Zeitouni, A Friberg, RJ Zatorre** CANADA	**Experience-dependent modulation of feedback integration during singing: role of the right anterior insula**
100	**M Lemay, N Bourguignon V Frak, I Richard, M Robert, T Nazir, G Cadoret, D Shiller** CANADA	**Hearing action verbs affects postural control**
143	**J Danna, V Paz-Villagrán, E Thoret, C Gondre, R Kronland-Martinet, A Capel, C Petroz, P Pierre, O Cazès, A Limozin, J-L Velay** FRANCE	**Sonifying handwriting movements as real-time auditory feedback for the rehabilitation of dysgraphia**
158	**C Neufeld, A Namasivayam, P van Lieshout** CANADA	**Bimodal sensory influence in speech control**

Poster Session III
Communications par affiche III

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Theme V: Motor Control and Recovery from Injury

Poster board numbers indicated in left column. Authors will present posters on ***Tuesday July 16 from 12:00 to 14:00.***

No.	AUTHORS	TITLE
21	**N Dounskaia, W Wang** USA	**Preferred joint control pattern during 3D arm movements with abundant degrees of freedom**
30	**R Sleimen-Malkoun, JJ Temprado** FRANCE	**A proof of concept approach towards a constrained-led bimanual rehabilitation strategy of inter-limb interactions following stroke**
39	**AJ Pearce, B Adair, GA Tooley** AUSTRALIA	**A novel treatment for Mal de Debarquement syndrome. A case study using transcranial direct current stimulation**
50	**M Markova, A Zelena, A Krobot, B Kolarova** CZECH REPUBLIC	**Does treadmill walking with metronome have any effect on lower limb loading within both stance and automatic postural reaction in stroke patients?**
59	**MJ Wiest, DF Collins** CANADA	**Central contribution to "extra torque" during neuromuscular electrical stimulation**
61	**DE Haladay, C Chowdhary** USA	**Comparison of electromyographic abdominal muscle activity during abdominal muscle performance tests performed in two different planes**
73	**A Jongsma, G Mochizuki, A Mansfield, WE McIlroy** CANADA	**The relationship between cadence, step length, gait velocity, and impairment post-stroke**
74	**LM Morais, C Teixeira-Arroyo, MP Pereira, RA Batistela, PCR Santos, E Lirani-Silva, L Simieli, LTB Gobbi** BRAZIL	**Comparison between different stages of Parkinson's disease on functional mobility, clinical and cognitive parameters**
75	**J Baltich, V von Tscharner, BM Nigg** CANADA	**Reliability of a novel method to quantify postural control**
77	**M Villeneuve, V Penhune, A Lamontagne** CANADA	**Coordination of finger movements improves after piano training sessions in chronic stroke**
78	**A Centen, WE McIlroy, SH Scott, G Mochizuki** CANADA	**Robotic assessment of active motor control in stroke survivors with spasticity**
82	**AR Marinho, AMF Barela, ML Celestino, MR Camargo, MR Popovic, MC Verrier** CANADA	**The effects of the aquatic environment on upright stance control: a pilot study comparing COP displacements in water and on dry land**
85	**MR Camargo, JA Barela, ML Celestino, AMF Barela** BRAZIL	**Effects of body weight unloading on ground reaction force measurements during walking**
93	**O Habib Perez, G Mochizuki** CANADA	**Cortico-muscular coherence post stroke in patients with upper limb spasticity**
96	**G Aravind, A Lamontagne** CANADA	**Reduced perceptual-motor abilities contribute to altered obstacle avoidance in persons with visuospatial neglect**
99	**CY Chen, J Heathcock** USA	**Arm and hand control during the emergence of reaching in infants with neonatal stroke**
101	**Y Mullié, F Loiselle, P Gourdou, C Duclos** CANADA	**Role of proprioceptive information on stability during gait with healthy and hemiparetic people**
102	**N Sarabon, M Voglar** SLOVENIA	**Strength of the trunk muscles correlates moderately with the timing of anticipatory postural adaptations**
109	**D Green, V McClelland, T Page, M Weinstein, D Ben-Bashat, G Charles-Edwards, GJ Barker, D Birtles** UNITED KINGDOM	**Temporal coupling of bimanual skills in children with hemiplegic cerebral palsy**

Poster board numbers indicated in left column. Authors will present posters on ***Tuesday July 16 from 12:00 to 14:00.***

No.	AUTHORS	TITLE
110	**C O'Reilly, R Plamondon** CANADA	**Linking brain stroke susceptibility with some movement characteristics**
114	**JL Chen, S Fujii, G Schlaug** CANADA	**The role of auditory feedback in improving arm reaching in chronic stroke**
116	**JB Doan, N de Bruin, MJ Amatto, J Bocksnick, LA Brown** CANADA	**Ice skating visual stimulation primes postural response in an unexpected perturbation**
120	**MP Furmanek, K Slomka, G Juras** POLAND	**The effect of cooled gel-packs on the knee joint position sense in healthy individuals**
123	**SA Holmes, B Whatley, A Yusuf, R Sussex, L Koski** CANADA	**The application of rTMS to improve motor impairment in Multiple Sclerosis: a pilot study**
126	**NEJ Signal, G Lewis, D Taylor, K McPherson** NEW ZEALAND	**Are TMS-derived measures reliable markers of neural plasticity in people with stroke?**
128	**S Berman, DG Liebermann, MF Levin** ISRAEL	**Shoulder – trunk coordination using the arm-plane representation for reaching movements in patients with stroke**
134	**S Lauzière, C Miéville, R Aissaoui, C Duclos, S Nadeau** CANADA	**Post-adaptation kinetic changes following walking on a split-belt treadmill with asymmetrical belt speeds in healthy individuals**
138	**AK Vafadar, J Cote, PS Archambault** CANADA	**Inter-rater and intra-rater reliability of shoulder position sense measurement tools**
139	**A Parent, M Raison, G Letellier, P Marois, C Mercier, L Crevier, M Laberge, L Ballaz** CANADA	**Twenty five years experience at the Sainte-Justine Hospital of selective dorsal rhizotomy based on clinical observations instead of intraoperative electrophysiological monitoring**
153	**FG Martinez, K Rosa, C Ely, RL Chaves, V Arnt, K Alves, G Brodt, J Loss, L Tartaruga** BRAZIL	**Trunk muscle activity during different upper limb exercises in anticipatory postural adjustments: a quantification for periodization of therapeutic exercises**
159	**JK Carlyle, G Mochizuki** CANADA	**Dissociation between EMG activation ratio and active range of motion in individuals with wrist flexor spasticity**
160	**V Gray, C Pollock, J Wakeling, T Ivanova, SJ Garland** CANADA	**Patterns of muscle coordination during stepping responses post-stroke**
166	**CL Pollock, TD Ivanova, A Gallina, TM Vieira, SJ Garland** CANADA	**Ankle plantarflexor activity during standing perturbations in people following stroke as measured with high density surface electromyography**
168	**ML Celestino, GL Gama, M Fugita, AMF Barela** BRAZIL	**Analysis of children with cerebral palsy walking with partial body weight support system on static surface**
172	**SL Jones, MA Busa, J Averill, REA van Emmerik** USA	**Postural stability is reduced in people with Multiple Sclerosis due to walking-imposed fatigue**
175	**MA Busa, SL Jones, REA Van Emmerik** USA	**Multiscale entropy identifies postural control changes in persons with multiple sclerosis**
178	**A Sarcher, M Raison, M Laitenberger, M Lemay, L Ballaz, PA Mathieu** CANADA	**Muscular co-activation and joint torque during elbow flexion-extension in healthy adults: towards a tool to quantify spasticity during voluntary movement**
181	**J Averill, S Jones, R Van Emmerik** USA	**Effect of a three week tai chi intervention on dynamic postural stability in individuals with multiple sclerosis**

Poster board numbers indicated in left column. Authors will present posters on ***Tuesday July 16 from 12:00 to 14:00.***

No.	AUTHORS	TITLE
182	**MB Gois Júnior, M Bomfim Santos, S de Andrade Melo, S Schneiberg** BRAZIL	**Efficiency of Klapp method to improve postural control in patients infected by HTLV-1: a baropodometric analysis**
183	**MB Gois Júnior, AF Santos Reis, S de Andrade Melo, S Schneiberg** BRAZIL	**Postural stability analysis in teenagers with severe deafness and teenagers with artificially induced deafness**
184	**MB Gois Júnior, AP Silva dos Santos, S de Andrade Melo, S Schneiberg** BRAZIL	**The Klapp method decreases body sway on standing balance in teenagers with idiopathic scoliosis**
186	**AK Blanchette, K Moïn-Darbari, MF Levin** CANADA	**The tonic stretch reflex threshold as a measure of ankle plantarflexor post-stroke spasticity: a reliability study**
188	**MT Robert, R Guberek, H Sveistrup, MF Levin** CANADA	**The effectiveness of a reach-to-grasp task for motor learning in children with cerebral palsy**
196	**MC Baniña, AA Mullick, MF Levin** CANADA	**Altered obstacle avoidance behaviour in individuals with good arm recovery after stroke**
197	**J Maglio, C Quat** AUSTRALIA	**Holistic Circus Therapy: Incorporating adaptive instruction and equipment**

Theme VI: Motor Control and the Performing Arts

Poster board numbers indicated in left column. Authors will present posters on ***Tuesday July 16 from 12:00 to 14:00.***

No.	AUTHORS	TITLE
14	**F Karpati, C Giacosa, V Penhune, NE Foster, KL Hyde** CANADA	**Gray matter differences in professional dancers**
33	**C Giacosa, F Karpati, V Penhune, NE Foster, KL Hyde** CANADA	**White-matter differences in professional dancers**
35	**EO Boyer, Q Pyanet, S Hanneton, F Bevilacqua** FRANCE	**Sensorimotor adaptation to a gesture-sound mapping perturbation**
36	**SS Wolff, AN Haas** BRAZIL	**The effects of dance classes in the motor control of stroke patients in Southern Brazil**
38	**Y Yamamoto, K Yokoyama, M Okumura, A Kijima, K Kadota, K Gohara** JAPAN	**Intentional switching dynamics in Japanese martial arts**
40	**MC van der Steen, FT van Vugt, PE Keller, E Altenmüller** GERMANY	**Separating perception and production abilities in auditory-motor processing of musician's dystonia patients**
45	**A Kijima, M Okumura, RC Schmidt, Y Yamamoto** JAPAN	**Interpersonal distance emerges as an "not-to-lose" strategy in a play-tag sport game**
48	**C Ioannou, M Klämpfl, B Lobinger, M Raab, E Altenmueller** GERMANY	**Neuropsychological characteristics among dystonic musicians: A comparative investigation into neuropsychological trigger factors and treatment effects between musicians and athletes**
49	**LH Baer, J Bailey, T Gralnik, Min Tae Park, M Mallar Chakravarty, KZH Li, VB Penhune** CANADA	**The relationship between age of onset of musical training and finger tapping performance**
54	**PJ Stein, DS Young, JT Dennerlein, WH Hsu, G Faber, EL Saltzman** USA	**The effect of precision requirements in violin bowing tasks on torque loading of the bowing arm: an inverse dynamic analysis**
66	**E Schoonderwaldt, M Demoucron, E Altenmüller** GERMANY	**Auditory-motor interaction in violin bowing: Timing, coordination and pattern formation**
91	**F Manning, M Schutz** CANADA	**Movement timing determines perceived auditory timing in a sensorimotor integration task**
94	**C Palmer, E Koopmans, F Spidle** CANADA	**Postural sway in performing vocal duets: Effects of visual and acoustic cues**
115	**D Green, Y Farquharson** UNITED KINGDOM	**The Magic of Movement: Integrating magic into rehabilitation for children with hemiplegia**
119	**DJ Cameron, J Choi, AM Marca, JA Grahn** CANADA	**Synchronizing tapping with the beat of complex auditory sequences**
142	**JM Solomon, CM Theseira, FB Sapian** INDIA	**Comparison between visual, auditory and visuoauditory cueing on timing of movement**
146	**C López-Ortiz, K Doshi, JMS Simkowski, D Gaebler-Spira** USA	**Motor learning of classical ballet with feedback of reduced dimension in children with cerebral palsy**
147	**M Segado, A Hollinger, R Zatorre, V Penhune** CANADA	**Auditory motor integration in cello players**