PennState

Progress in Clinical MOTOR CONTROL

Neurorehabilitation

University Park, Pennsylvania

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https://hhd.psu.edu/college/motor-control-conference

Welcome to the Progress in Clinical Motor Control: Neurorehabilitation I.
Pennsylvania State University, 2018

The field of neurorehabilitation includes contributions from scientists in basic science, engineering science, and clinical science, and this forum brings together top scholars from all three areas. Historically, it is common for scientists from each of these domains to share ideas with one another at domain-specific conferences, such as the Society for Neuroscience, the American Society for Neurorehabilitation, and the Engineering in Medicine and Biology Society. While some of these scientists may occasionally cross-over to another domain, it is rare for one conference to bring together all three domains. The first conference on Progress in Clinical Motor Control achieves this goal by integrating cutting edge findings across each domain and promote discussion and debate about how best to integrate this information into clinical neurorehabilitation.

The clinical domain is comprised of practitioners and scientist physicians, physical and occupational therapists, speech pathologists, and neuropsychologists. The basic science domain is comprised of scholars in neuroscience, biomechanics, and psychology focused on understanding basic mechanisms of cognition and motor control that are impacted by central nervous system lesions. The engineering domain includes biomedical and mechanical engineers focused on developing human-brain-machine interfaces and devices to promote recovery in neurorehabilitation. Such devices and interfaces are rapidly impacting both clinical rehabilitation and rehabilitation science. Never has a single conference brought together such a distinguished group of top scientists in these three areas of neurorehabilitation related science and technology. The First conference on Progress in Clinical Motor Control: Neurorehabilitation focuses on the challenges of applying basic, clinical, and engineering approaches to improving the current and future potential for neurorehabilitation.

Organizing Committee

Chair: Robert L. Sainburg, PhD OTR
Professor of Kinesiology and Neurology, Director of Center of Movement Science and Technology, Penn State University.

Julius P. Dewald, PhD, PT
Chair, Department of Physical Therapy and Human Movement Sciences, Northwestern University.

Mindy F. Levin, PhD, PT
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Robert A. Scheidt, Ph.D.
Professor of Biomedical Engineering, Director Neuromotor Control Laboratory, Marquette University

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João Eduardo de Araujo, PhD, PT
Professor of Physical Therapy, Ribeirão Preto Medical School of the University of São Paulo

The National Center of Neuromodulation for Rehabilitation presents the Keynote Lecture.
William Zev Rymer, MD, PhD.
"Current state and future of Clinical Motor Control Research"

Dr. Rymer serves as Director of the Sensory Motor Performance Program, a position he has held since 1987, and Director of Research Planning Engineering in Neuroscience at the Shirley Ryan AbilityLab (Formerly the Rehabilitation Institute of Chicago) . In addition to his research roles at RIC, Dr. Rymer holds appointments as Professor of Physiology and Biomedical Engineering at the Northwestern University Feinberg School of Medicine. His laboratory receives support from the National Institutes of Health, the Department of Education's National Institute on Disability and Rehabilitation Research (NIDRR), and a number of research-oriented foundations. Dr. Rymer has played a major role in integrating the fields of Neuroscience, Physiology, Bioengineering, and Rehabilitation to address research focused on clinical rehabilitation. He is recognized for his tremendously supportive roles in mentoring generations of young scientists. Dr. Rymer earned his medical degree from Melbourne University and his PhD in Neurophysiology from Monash University, both in Australia. After postdoctoral training at the National Institutes of Health and Johns Hopkins University Medical School, he became an Assistant Professor of Neurosurgery and Physiology at the State University of New York, Syracuse. In 1978, he came to Chicago as an Assistant Professor of Physiology at the Feinberg School of Medicine at Northwestern University, and he remained as a primary faculty member in Physiology until his appointment at the RIC.

Recognizing the career and mentorship of Claude Ghez, M.D.

This conference will also feature a tribute to one of the most influential contemporary scientists in the Neurobiology of Motor Control, CLAUDE P.J. GHEZ, M.D. Over many decades, Dr. Ghez's research has investigated the control of movements in animals and humans with specific neurological lesions. His research continues to investigate the sensory mechanisms involved in the learning and control of movements in typical human subjects and patients with specific neurological disturbances. His current research is informed by his earlier findings that (1) even simple reaching movements involve separate control actions responsible for trajectory formation and stabilized final positions; and (2) that visual and proprioceptive sensory signals play different roles in ongoing feedback control and motor learning. Their current research focuses on two areas. (1) How interactions of motor and sensory impairments in hemiparesis due to stroke produce specific impairments in the learning and control of trajectory and stabilization of limb position. (2) The use of simple sonic information as well as musical material as a framework for encoding the rich multidimensional information constituting posture and movement to develop an 'auditory kinesthesia' training paradigm. Claude is well-known for his insightful and clever psychophysical paradigms that have helped to unravel the processes underlying motor control and learning. He has contributed to the development of many scientific careers in both basic and clinical science. We will have the chance to thank him for his excellent mentorship at an optional dinner-tribute held during the conference.

Progress in Clinical Motor Control I: Neurorehabilitation

Monday, July 23, 2018		
12:00 – 2:00 pm	**Registration**	**Past Present & Future**
12:30 PM	**Opening Comments**	
1:00 pm – 2:00 pm	**The National Center of Neuromodulation for Rehabilitation. Keynote Lecture**. William Zev Rymer, MD Ph.D. *Current state and future of Clinical Motor Control Research*	
2:00 pm – 2:15 pm	**Break**	
2:15 pm – 3:45 pm	**Session: Motor Learning and Clinical Motor Disorders.** Moderator: Mark Latash, Ph.D. Speakers: Pablo Celnik, MD, Ph.D., Ludo Max, Ph.D., CCC-SLP, Jonathan Wolpaw, MD	
3:45 pm – 5:15 pm	**Session: Cognition and Clinical Motor Disorders.** Moderator: Paul Eslinger, Ph.D. Speakers: Pietro Mazzoni, MD, PhD, Maria Felice Ghilardi, MD, Laurel Buxbaum, Ph.D.	
5:15 pm – 5:30 pm	**Break**	
5:30 pm – 6:30 pm	**Session: Motor Control and Clinical Motor Disorders.** Moderator: Carolee Winstein, PT, Ph.D. Speakers: James Gordon, PT, Ed.D., Claude Ghez, MD.	
7:00 pm – 9:00 pm	**Cocktail Reception Sponsored by Aretech** **(At Nittany Lion Inn)**	

Tuesday, July 24, 2018		
7:30 am – 8:00 am	**Continental Breakfast**	**Basic Motor Control and Clinical Motor Disorders**
8:00 am – 9:45 am	**Session: Sensory Function and Clinical Motor Disorders.** Moderator: Mindy Levin, PT, Ph.D. Speakers: Netta Gurari, Ph.D., Sean Dukelow, MD, Ph.D. , Robert Scheidt, Ph.D., Helen Cohen, OT, Ed.D.	
9:45 am – 11:30 am	**Session: Reflex Modulation and Clinical Motor Disorders.** Moderator: Brian Schmit, Ph.D. Speakers: Alison Hyngstrom, Ph.D., Stephen Scott, Ph.D., Rick Segal, PT, Ph.D., Mindy Levin, PT, Ph.D.	
11:30 am – 1:00 pm	**Lunch and Posters**	
1:00 pm – 2:30 pm	**Session: Posture-Locomotion and Clinical Motor Disorders.** Moderator: Stephen Piazza, Ph.D. Speakers: Mark Rogers, PT, Ph.D., Jonathan Dingwell, Ph.D., Keith Gordon, Ph.D.	
2:30 pm – 2:45 pm	Break	

2:45pm – 4:15 pm	**Session: Brain Mechanisms of Motor Recovery Following Stroke**. Moderator: Leo Cohen, MD, Ph.D. Speakers: Sook-Lei Liew, OT, Ph.D., George Wittenberg, MD, Ph.D., Cathrin Buetefisch, MD, Ph.D.	**Clinical Conditions**
4:15 pm – 5:45 pm	**Session: Parkinson's Disease and Clinical Motor Control.** Moderator: Daniel Corcos, Ph.D. Speakers: Xuemei Huang, MD, Ph.D., David Vaillancourt, Ph.D., Scott Cooper, MD, Ph.D.	
5:45 pm – 6:45 pm	**Poster Session**	
7:00 pm – 9:30 pm	**Dinner Tribute to Claude Ghez, MD**	
	Wednesday, July 25, 2018	
7:30 am – 8:00 am	**Continental Breakfast**	**Clinical Conditions**
8:00 am – 9:30 am	**Session: Pediatric Clinical Motor Disorders.** Moderator: David Good, MD. Speakers: Diane Damiano, PT, Ph.D., Andrew Gordon, Ph.D., Patti Davies, OTR, Ph.D.	
9:30 am – 11:00 am	**Session: Spinal Cord Lesions and Clinical Motor Control.** Moderator: Cristian Cuadra, PT, MSc. Speakers: Monica Perez, PT, Ph.D, James Abbas, Ph.D., Jacob McPherson, Ph.D.	
11:00 am – 11:15 am	**Break**	
11:15 am – 12:45 pm	**Session: Brain Machine Interface and FES for functional recovery in SCI.** Moderator: Megan Vidt, MD, Ph.D. Speakers: Andrew Schwartz, Ph.D., Lee Miller, Ph.D., Robert Kirsch, Ph.D.	
12:45 pm – 2:00 pm	**Lunch and Posters**	
2:00 pm – 3:30 pm	**Session: Device mediated approaches to promote recovery in stroke.** Moderator: Robert Scheidt, Ph.D. Speakers: Jules Dewald, PT, Ph.D., Dave Reinkensmeyer, Ph.D., Eugene Tunik, PT, Ph.D.	**Technology and Applications**
3:30 pm – 3:45 pm	**Break**	
3:45 pm – 5:30 pm	**Session: Discussion and Debate – Realism vs. Idealism in Clinical Rehabilitation Research.** Moderator: Dave Reinkensmeyer, Ph.D Speakers: Steven L. Wolf, PT, Ph.D., Edelle Field-Fote, PT Ph.D, Jules Dewald, PT, Ph.D.	
5:30 PM	**Closing Reception and Posters**	

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Authors: Phillip C. Desrochers [1], Alexander T. Brunfeldt [1], Christos Sidiropoulos [3], Richard R. Neubig[4], Florian A. Kagerer [1,2]

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Authors: Saeed Arsham, Ph.D.[1], Fatemeh Keshvari[2]

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Authors: Jiali Liang, Krista Wilkenson, PhD, Robert Sainburg, PhD OTR.

95 Comparison of reach-to-grasp movement kinematics in real and virtual reality environments

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98 Sensory assessment of stroke patients

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99 Sense of effort: right and left hand sensitivity to proprioceptive feedback.

Authors: Yadrianna Acosta-Sojo[1], Bernard Martin[1]

Trunk movements in healthy individuals under different reaching speeds and locations.

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Stroke survivors often experience hemiparesis after stroke, which is characterized by muscular weakness on one side of the body. However, because of the redundancy in the human body, stroke survivors often adopt atypical ‘compensatory’ movement patterns for activities of daily living. A specific example of this compensation during reaching is using trunk motion to compensate for arm impairment, which can be detrimental to upper limb motor recovery. However, the dependence of this compensation on contextual factors such as reach amplitude and speed is not fully understood. The goal of this study was to evaluate how trunk displacement is affected by reach amplitude and reach speed in unimpaired individuals. Ten college-aged participants had their maximum reach distance measured, or the distance from the edge of the table to the end of their index finger taken along the midline while maintaining an upright posture. Reach amplitude was manipulated by placing targets at 60%, 80%, 100%, 120%, and 140% of this maximum reach distance. Participants were asked to make back and forth reaching movements toward all five targets. Reach speed was manipulated by asking participants to reach to the beat of a metronome, with speeds of 80, 120, and 160 beats per minute. At each speed, we asked participants to reach for the targets in two sequences – either from nearest to farthest or farthest to nearest. These six unique conditions were repeated in 8 trials per block. Understanding how healthy individuals modify trunk motions when reaching to various distances is critical to understanding deficits in stroke survivors and developing new strategies for motor recovery.

The contribution of motor overflow on interference in asymmetric hand movements.

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Previous work in our lab has shown that increasing force demands during bimanual reaching results in a dose-response in interference when one hand experiences a visuomotor perturbation. One interpretation of these results is that the updated internal model for the perturbed hand is shared with that of the contralateral (non-visible) hand. However, an alternative explanation may suggest inter-hemispheric connections produce a tendency for both limbs to generate similar amounts of force, or motor overflow. Our aim was to determine the relative contribution of each factor during a bimanual interference task. Therefore, we had participants perform a bimanual reaching task without a visual perturbation, but rather had them reach, with their right hand, to targets at locations that matched the endpoint of the visually perturbed movements in the first study. We hypothesize that if interference is solely due to motor overflow, the amount of interference will be the same as our initial study. However, if there is less interference, this would suggest that interference is due, at least in part, to a shared internal model of a novel visuomotor workspace.

Right-handed participants (n=30) performed a bimanual center-out reaching task using a KINARM endpoint robot to two peripheral targets either 90o or 270o (distance 10cm). Participants were provided visual feedback of hand position with two cursors, but vision of the hands was occluded. Following a visual baseline, the cursor display of the left hand was removed, and participants were instructed to move to where they thought they would hit the target. The exposure phase consisted of 140 trials with a 40o rotation in target location for the right hand. We modulated task kinetics by applying a restoring force at the manipulanda handles directed toward home positions. Participants were randomly assigned to one of three groups: 0-, 30-, or 60-N/m. Spatial interference was assessed using initial directional error (IDE) and lateral endpoint error (EPX), as well as the lateral force applied to the robot manipulandum in the left hand and peak velocity (LFP) and movement offset (LFO).

Neither IDE, nor LFP in the left hand were different among groups during the exposure phase; whereas both EPX and LFO were higher in the two groups receiving the spring force. In contrast to our initial study, where group differences were seen in IDE and LFP, we conclude that task dynamics are incorporated into a new internal model during the planning phase of movement. Moreover, EPX and LFO did not show the dose-response observed in the initial study, further suggesting bimanual interference during reaching task have a component tied to adaptation.

Effect of an antigravity passive assistive force on shoulder neuromuscular activity.

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Introduction: Neuromuscular disorders affecting the shoulder can impair movement ability and strength [1] even after surgical intervention [2]. Several mechanically passive assistive devices have been developed to enhance shoulder function [3,4], but the effect of such devices on neuromuscular coordination is unclear. We conducted a pilot study to determine the effect of a mechanically passive antigravity assistive force on shoulder muscle activity in healthy young adults during shoulder elevation movements. We hypothesized that activations of muscles that generate positive shoulder elevation (SE) moments would be lower with assistance than without.

Materials and Methods: Four able-bodied subjects (2 female, 2 male; height=170.8”Ą7.6 cm, mass=75.2”Ą17.7 kg) were seated below a mounted elastic spring (Speedaire 5YAP0). The spring applied an upward force, scaled to the subject”Æs mass, through a cable connected to a Velcro cuff on the subject”Æs dominant arm at approximately 18 cm from the glenohumeral joint center. Subjects each performed 20 trials of a scaption and abduction motion both with and without assistance (80 trials total); the order of test conditions was randomized across subjects. The target maximum SE angle (90 degrees) and duration (2 seconds) were constrained with a physical target and metronome. We used motion capture (OptiTrack) and electromyography (EMG, Noraxon) systems to measure upper limb kinematics and EMG of nine muscles crossing the shoulder. EMGs were smoothed and normalized by peak EMG from maximum voluntary contractions to compute activation (0=inactive, 1=maximally active). Mean activations during the second half of the elevation phase were compared between assisted and unassisted trials using paired Student”Æs t-tests.

Results: For abduction, muscles that showed significant activation change (p”Ü 0.05) were the anterior deltoid (Unassisted (U): 0.12 ”Ą 0.07; Assisted (A): 0.08 ”Ą 0.05), middle deltoid (U: 0.12 ”Ą 0.03; A: 0.08 ”Ą 0.05), supraspinatus (U: 0.11 ”Ą 0.09; A: 0.08 ”Ą 0.07), and infraspinatus (U: 0.04 ”Ą 0.02; A: 0.03 ”Ą 0.02). For scaption, muscles that showed significant activation change were the anterior deltoid (U: 0.09 ”Ą 0.05; A: 0.07 ”Ą 0.03), middle deltoid (U: 0.10 ”Ą 0.03; A: 0.07 ”Ą 0.03), and infraspinatus (U: 0.03 ”Ą 0.01; A: 0.03 ”Ą 0.02). Discussion and Conclusion: Activations were significantly lower in some, but not all, muscles that generate positive SE moments, consistent with our hypothesis. This study was limited by the number of subjects tested and high inter-subject anthropometry variation. Testing additional subjects in the future will help verify results found in this preliminary study.

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Kinematic precision of rapid wrist movements with and without visual feedback in able-bodied subjects and an upper limb amputee.

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Introduction: Amputees experience sensorimotor cortical reorganization following amputation [e.g. 1] that may interfere with their ability to control myoelectric prostheses, though other factors (e.g. absent visual feedback of movements) could also affect their motor commands. Rapid feedforward movements, performed too quickly to involve substantive influence from (lack of) sensory feedback, may be useful for isolating the effect of cortical organization on motor commands [2]. We conducted a pilot study to compare kinematic precision between rapid wrist movements performed with and without (peripheral) visual feedback of the hand. Methods: Four able-bodied subjects and one subject with congenital amputation (with ~1 cm residual wrist) were seated in front of a TV monitor. A twin axis electrogoniometer (Biometrics LTD, SG 65) was attached across able-bodied subjects' dominant (amputee's residual) wrist to record wrist flexion/extension angle at 3000 Hz. We photographed each subject's (amputee's intact) wrist in four target postures (30o and 50o of both flexion and extension). In each trial, subjects were shown all photos, one at a time and in a randomized order, and instructed to move their wrist as fast as they could to match the displayed posture. Subjects performed 10 trials for each of two test conditions – with their hand visually occluded (i.e. in a box) and non-occluded – randomizing the order of condition across trials. Movement onset and offset times were computed using an angular velocity threshold (15°/sec). Data were normalized temporally to permit comparison among trials. Results: The mean (M) and standard deviation (SD) of movement duration were significantly different between visually occluded (M=386 ms, SD=110) and non-occluded (M= 348 ms, SD=58) trials (paired t-test: $p<0.05$). However, there was no difference in end angles between vision conditions (paired t-test: $p>0.05$). A comparison of kinematic trajectories using statistical parametric mapping [3] (SPM, two-tailed paired t-test) showed that the magnitudes of the wrist angles for both conditions were very similar. However, variability (SD) was significantly greater during visually occluded trials from 20-50% of the rapid movement ($p=0.03$). Qualitatively, end-angle precision was similar between able-bodied subjects and the amputee.

Discussion and Conclusions: Visually occluded movements lasted longer and were more variable than non-occluded movements. However, end-angle precision was the same between vision conditions. This suggests that vision of the hand during rapid movements may not influence the movement outcome, but the way in which the outcome is achieved.

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Functional versus analytical movements: different mirror therapy effects?

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Introduction: Mirror therapy (MT) is commonly used in routine practice in neuro rehabilitation treatments and it is one of the techniques that have been scientifically proved to enhance motor recovery after stroke (Zen. 2018). Studies performed in healthy subjects and in stroke patients show that mirror illusion modulates cortical and corticospinal excitability (Naish . 2014, Kang 2012). However, it remains still unclear if certain movements induce greater corticospinal excitability than others. Some clinical trials had been interested in implementing functional tasks in front of the mirror box hypothesizing that functional movements could promote better recovery after stroke. The aim of this study was to assess if different kind of movements could induce greater corticospinal excitability than others.

Methods: Experiment 1: Surface electromyographic signals (sEMG) were recorded in 10 healthy subjects in both arms under the illusion caused by a mirror box. The arm inside the mirror box remained at rest (resting arm), whereas the arm outside the mirror box (moving arm) performed three types of movements: i. analytical movements, ii. Functional bimanual non-cooperative movements, and iii. Functional bimanual cooperative movements. The subject observes the movement performed by the moving arm and the reflection of the mirror, having the visual illusion of bimanual movements. Experiment 2: The same protocol as experiment 1 was carried on in a chronic stroke patient after 8 weeks of specific training with mirror therapy.
Results: Experiment 1: sEMG signal in the resting arm showed activity related to mirror illusion in this single session. Preliminary results showed limited differences between bimanual cooperative functional movements, analytical movements and bimanual non cooperative movements. Experiment 2: After eight weeks of MT training, chronic stroke patient presented a clear activation in the palsy upper limb muscles related to the movement illusion. Reaching a level of activation similar to that obtained while performing active movements with the paretic limb. As for healthy subjects, EMG activity was not clearly different between analytical and bimanual cooperative movements, but the level of activity seemed more related to mirror training performed.

Conclusion: Our results confirm that mirror movement illusion evoke corticospinal excitability even for a chronic stroke patient. And they suggest that the effect of mirror illusion depend more on training effect that movement modalities effect.

Role of the corpus callosum in mediating interlimb transfer of motor skills: insights from callosal patients.

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Learning a motor skill can generalize to another scenario involving, for example, a different motor task or a different limb. The generalization of motor learning across limbs, known as interlimb transfer, has been well demonstrated by research on short-term sensorimotor adaptation, yet underlying neural mechanisms remain unclear (Criscimagna-Hemminger et al. 2003; Perez et al. 2007). Amongst the various theoretical models, many of them highlighted the corpus callosum (CC) as a key brain structure mediating interlimb transfer (Taylor and Heilman 1980; Parlow 1989). However, Criscimagna-Hemminger et al. (2003) reported interlimb transfer of force-field adaptation in a split-brain patient with complete commissurectomy. Here we aimed to expand on this research by studying a range of CC pathologies to clarify the role of the CC in interlimb transfer. According to the callosal access model, we hypothesized decreased interlimb transfer in CC patients as compared to healthy controls. After assessing baseline performance in a reaching task, we used a confirmed prismatic perturbation procedure to assess interlimb transfer: participants wore prisms (which deviated the visual field by 17°) while reaching for 100 trials with the dominant arm, before subsequent testing of the unexposed non-dominant arm looked to examine interlimb transfer. Preliminary data indicate normal prismatic adaptation and significant interlimb transfer for one patient with CC agenesis, as well as another patient with CC lesions following a ruptured brain aneurysm. Whilst more controls and patients with CC lesions must be examined, our preliminary findings fall in line with the research done by Criscimagna-Hemminger et al. (2003) as it suggests that adaptation with the dominant arm can generalize to the non-dominant arm through ipsilateral corticospinal projections.

Independent visuomotor control of each arm during bimanual coordination.

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We have previously shown interlimb asymmetries in sensorimotor performance and provided evidence for hemispheric lateralization of neural mechanisms underlying unimanual coordination. Studies on bimanual coordination have suggested that bimanual tasks can recruit a single unique neural control of movement mechanisms (Kelso, 1979; Diedrichsen, 2007). We now explore whether this single unique neural controller of bimanual coordination: (1) alters interlimb asymmetries present in unimanual movements, and if so how?; (2) asses movement errors of a shared common object transported rather than individual contribution of each arm. We predict that the single unit control should be implemented through both arms, thus both of these modulations would occur. Alternatively, there is no effect, or no presence, of this single unique neural controller of bimanual coordination, thus each arm is controlled independently maintaining interlimb differences and recruiting independent corrections. In the initial experiments, our volunteers, healthy college students, performed targeted reaching tasks to compare sensorimotor performance between unimanual and bimanual conditions. In bimanual conditions, we considered both independent (one object per arm), and shared (one common object) task. We also included conditions for movements in hand (same direction) and joint (mirror image) space. In the later experiments, we focused on bimanual task of transporting a shared object and tested whether movement errors are being evaluated on the level of one single unit or on the level of each individual arm effector. For this purpose, we modulated the gain of each arm's contribution to perpendicular error of a shared object during movement in such a way that our subjects were not consciously aware of the manipulation. Our data show that interlimb differences in sensorimotor performance persist during bimanual coordination across both independent or shared task, and hand and joint space conditions. Further, gain alternations in a shared object bimanual condition showed that reductions in contribution to error produced increases in movement variance for each hand, independently. Interestingly, the pattern is not symmetric; such that gain induced reductions in movement variability were more consistently sustained for the dominant, but not the nondominant arm. These results show vigilant and independent assessment of each arms' contribution to movement of a shared object during bimanual coordination, which questions the idea that both arms are recruited into a single synergistic system for visuomotor control during bimanual reaching.

The neuromuscular mechanisms and motor learning adaptations contributing to cross education in the upper and lower limbs.

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INTRODUCTION: Cross education is the strength gain transferred to the homologous, contralateral limb following unilateral training. Although widely studied, neural adaptations such as a change in motor unit firing rates have remained equivocal in the literature. Furthermore, the contribution of motor learning is often overlooked. The present study examined neural adaptations in the contralateral limb following unilateral resistance training, and evaluated the contribution of motor learning to cross education.

METHODS: Forty healthy adults (20M, 20F) were randomly assigned to complete a 6-week unilateral training program for either dominant limb wrist flexion or dorsiflexion. Training consisted of dynamic exercises performed 4x/week at 80% maximal force. Testing was performed twice pre-training, post-training, and following 6-weeks of detraining (retention). Each session examined all four limbs (trained, contralateral, untrained dominant, untrained non-dominant). Force and surface electromyography were recorded during maximal and submaximal contractions to assess strength, central drive, motor unit firing rates, and force variability. Analyses of covariance compared the experimental limb (trained or contralateral) to the homologous control (dominant or non-dominant) of the alternate group at each session.

RESULTS: There were no significant differences between sexes. Contralateral strength increases of 11% (arm) and 15% (leg) resulted in greater strength in the contralateral limb at post-training compared to the control arm ($p=0.21$) and leg ($p=0.10$). Following continued strength increases for a total cross education of 18% (arm) and 22% (leg), the contralateral strength was greater than the control arm ($p<0.01$) and leg ($p=0.06$) at retention. The contralateral limb demonstrated increases in agonist RMS amplitude in the arm (6%, $d=0.16$) and leg (15%, $d=0.43$), V-wave amplitude in the leg (41%, $d=0.59$), and central activation ratio in the arm (1.2%, $d=0.52$). The force variability indicated the presence of motor learning in the contralateral limb.

CONCLUSIONS: Neuromuscular mechanisms mirrored force increases at post-training and retention testing substantiating the adaptations in central drive associated with cross education. However, no change in motor unit firing rates of the trained or contralateral limbs was observed. The continued strength increase at retention identified the presence of motor learning, which was confirmed by the force variability results. The amount of cross body transfer (contralateral/ipsilateral gain) was greater in the leg than arm at post-training indicating preferential transfer in the lower limb.

Quantitative Assessment of Interlimb Coordination in Persons with Hemiparesis.

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Background: Interlimb coordination is essential to the successful performance of daily tasks. Individuals with post-stroke hemiparesis often have difficulty performing these tasks due to limb weakness and inefficiency. The purpose of this study was to develop a quantitative measure of interlimb coordination capable of discriminating between unimanual, bimanual symmetric and bimanual asymmetric task performance as a proxy for recovery and change with intervention.

Methods: Ten adults post-stroke and ten age-matched controls performed 6 manual tasks twice in sitting while wearing 5 APDM Opal inertial sensors (Portland, OR) on the wrists, upper arms, and chest. Raw sensor data measuring acceleration, angular rate of change, and magnetism, were compared across 3 metrics (peak to peak amplitude, time, and frequency), then combined to create one similarity metric. Each segment was compared for each task and group using a novel algorithm. We focused on 3 comparisons: wrist to sternum; wrist to upper arm; and primary to secondary upper arms. Outputs for the 3 comparisons were compared across task type using a one-way Friedman test followed by a post-hoc Wilcoxon signed rank test. Differences between each control and age-matched post-stroke counterpart were analyzed using Mann-Whitney U tests.

Results: For controls, there were no significant differences between task type for the wrist to sternum comparison ($p=0.372$); significant differences were noted between tasks for the wrist to upper arm comparison ($\chi^2(2)=25.9$, $p<0.001$), and between the two upper arms ($\chi^2(2)=12.1$, $p=0.002$). Between controls and persons post-stroke, the wrist to sternum comparison revealed significant differences for all task types ($p< 0.001$); the wrist to upper arm comparison showed group differences ($p<0.001$), and the comparison between upper arms also revealed group differences (p<0:001; $p=0.034$). Persons post-stroke displayed greater differences between segments and involved the trunk more during task performance than controls.

Discussion/Conclusion: Preliminary findings suggest that this assessment and data processing algorithm quantitatively discriminates between manual tasks in controls. It also differentiates performance quality between controls and persons post-stroke by task, highlighting important group differences in interlimb coordination. The strength of this approach will be fully realized when compared to clinical outcome measures in a larger sample.

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Isometric force generation in one hand facilitates long latency, but not short latency reflexes in the opposite wrist.

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Although interhemispheric inhibition via transcallosal pathways is a well-known phenomenon, recent studies have found that when forces exceed approximately 70% of MVC, these interhemispheric interactions can result in increased cortical excitability in the opposite hemisphere (Perez and Cohen, 2008; Long et al., 2016). A recent study from our lab showed that when participants resisted a strong force at the finger of one arm, vigor (speed and frequency) of rhythmic radial-ulnar deviation movements in the contralateral arm increased, and this effect scaled with isometric force generated by the opposite arm. We now ask if the mechanisms mediating this increase in movement vigor are reflected in spinal and supraspinal reflexes. We examined this question using a perturbation task, in which participants were instructed to hold the position of their left wrists against a background flexor load, and on random trials a perturbation was applied to the wrist, eliciting a stretch reflex of the wrist flexors. Similar to the previous experiment, the contralateral force condition required participants to exert isometric force with their right index finger for the entirety of the trial. In a baseline condition required, the right arm did not exert force. EMG activity of the flexor and extensor carpi muscles of the left forearm was recorded and separated into intervals short-latency (M1: 20-45 ms post-perturbation) and long-latency (M2: 45-75 ms) intervals. We compared activity in these intervals to see if the contralateral force of the right arm altered the reflex response of the left arm. Our preliminary results suggest an interaction between contralateral force condition and reflex interval for the flexors, such that the M2 interval showed increased activity in the contralateral force condition compared to baseline, but M1 did not. This indicates a cortical, but not a spinal facilitation from contralateral isometric force generation, and may be related to inhibition of intercortical inhibition reported previously by Perez and Cohen (2008), and Long et al. (2016).

Functional Deficits in Chronic Stroke Depend On Extent of Contralesional Impairment And On The Side Of Brain Damage.

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We previously detailed the hemisphere dependence and specific behavioral nature of non-paretic arm motor deficits in patients with unilateral stroke. We now examine whether these deficits depend on hemisphere of damage and severity of contralesional paresis by quantifying the effect of unilateral stroke on clinical tests of motor function. We recruited 48 left hemisphere damaged (LHD) patients, 62 right hemisphere damaged (RHD) patients, and 54 age matched control participants. Measures of motor function included: 1) Jebsen-Taylor Hand Function Test (JTHFT), 2) Grooved pegboard test, and 3) Grip Strength. We measured the extent of contralesional impairment with the upper extremity component of the Fugl-Meyer (UEFM) assessment of motor impairment. Non-paretic arm motor deficits depended strongly on severity of contralesional arm impairment on all measures, but hemisphere specific deficits were only evident on some measures. LHD patients with severe paresis (UEFM < 28) took, on average, 112% longer to complete the JTHFT than control participants using the left non-dominant arm ($p < 0.0001$), while the severe RHD group took, on average, 61% longer than control participants using the right arm ($p < 0.0001$). Thus, stroke survivors with the most severe paretic arm impairment, who must rely on their ipsilesional arm for daily activities, have the greatest motor deficit in the non-paretic arm. We recommend remediation of this arm to improve functional independence in this cohort of stroke patients.

Effect of reach amplitude and speed on compensatory trunk movements in unimpaired individuals.

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Stroke survivors often experience hemiparesis after stroke, which is characterized by muscular weakness on one side of the body. However, because of the redundancy in the human body, stroke survivors often adopt atypical 'compensatory' movement patterns for activities of daily living. A specific example of this compensation during reaching is using trunk motion to compensate for arm impairment, which can be detrimental to upper limb motor recovery. However, the dependence of this compensation on contextual factors such as reach amplitude and speed is not fully understood. The goal of this study was to evaluate how trunk displacement is affected by reach amplitude and reach speed in unimpaired individuals. Ten college-aged participants had their maximum reach distance measured, or the distance from the edge of the table to the end of their index finger taken along the midline while maintaining an upright posture. Reach amplitude was manipulated by placing targets at 60%, 80%, 100%, 120%, and 140% of this maximum reach distance. Participants were asked to make back and forth reaching movements toward all five targets. Reach speed was manipulated by asking participants to reach to the beat of a metronome, with speeds of 80, 120, and 160 beats per minute. At each speed, we asked participants to reach for the targets in two sequences – either from 'near to far' or 'far to near'. These six unique conditions were repeated in 8 trials per block. Results showed that as expected, trunk displacement increased with reach amplitude. The effect of reach speed did not seem to affect the trunk displacement, but there was greater hysteresis at higher speeds– i.e., trunk displacement for the same target was higher for the far to near sequence, compared to the near to far sequence. Understanding how healthy individuals modify trunk motions when reaching to various distances is critical to understanding deficits in stroke survivors and developing new strategies for motor recovery.

Cognitive agency for rehabilitation of hand grasp performance.

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Clinical rehabilitation of hand grasp compromised by neuromuscular pathology is critical to improve performance of activities of daily living. Functional hand prostheses used following amputation or spinal cord injury can restore basic grasp but leave the user feeling disconnected from the device as a true extension of self. We hypothesize that greater cognitive integration between user and device is positively correlated with greater grasp performance. Cognitive agency is the sense one is the true author of one's movements and is apt for hand prostheses deployed as surrogates for intact hands.

Agency can be quantitatively measured from perceived compression of time-intervals between actions and consequences. We propose utilizing cognitive agency as an optimization criterion for determining operational parameters of a hand prosthesis. We have developed a virtual reality (VR) paradigm to investigate the sensitivity of agency and performance to systematic changes in operation of a virtual hand prosthesis. The VR environment provides a programmable interface for systematically altering agency through visual feedback of hand operation.

To our knowledge, incorporating cognitive perception with rehabilitation to improve functional performance has not been thoroughly examined. Demonstrating how individuals perform with greater agency will potentially provide a powerful basis for designing neurorehabilitation protocols that are more intuitive and efficient. If the functional connection between agency and performance is established, agency can be a highly viable criterion to optimize various modes of rehabilitation.

Currently, we have completed collecting data with over 15 healthy individuals performing reach-to-grasp tasks whereby the virtual hand motions or forces are tracked and displayed to the user. The base motions and forces are altered in the virtual environment through variations in speed, addition of noise, or gradually relying more on device automation. Our long-term objective is to develop a VR platform that facilitates the role of cognitive agency in creating advanced feedback controllers that optimize performance of assistive hand grasp devices.

Targeted memory reactivation during a daytime nap to enhance non-paretic arm skill performance in older adults with chronic stroke.

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Introduction: Sleep is an important component of motor memory consolidation and learning. A method known as targeted memory reactivation (TMR) involves replay of previously classically conditioned auditory stimuli during sleep to enhance the process of consolidation and subsequent performance. Results from our previous two studies have suggested that (1) TMR throughout the first two cycles of slow wave sleep during overnight sleep, as well as (2) throughout the entirety of a daytime nap, can enhance sensorimotor skill performance in healthy young adults. What is still unknown is whether TMR can enhance skilled upper extremity performance in individuals with stroke. Methods: Older adults with a history of stroke at least 6 months prior performed two sessions of a non-paretic arm throwing task separated by a one-hour period of napping, with half of all participants receiving TMR throughout the one hour. The task involved repetitive throwing to unique visuospatial targets, each of which was paired with a distinct auditory cue. During the application of TMR these cues were repetitively replayed. The primary and secondary outcomes of absolute and variable throwing error distance, respectively, were collected at four time points (baseline, post initial training session, post one-hour nap, and post second training session). Participants were divided into groups based on the inter-training interval: Napping+NoTMR, Napping+TMR. Results: Data has been collected for five participants. Preliminary results between the Napping+NoTMR (n = 2) and Napping+TMR (n = 3) groups suggest that auditory cues enhanced spatial accuracy compared to no cues. Further data collection and analysis are underway. Support: The American College of Sports Medicine Foundation.

Improving arm muscle activation in patients with severe chronic hemiparesis.

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Patients with severe chronic hemiparesis show inefficient muscle recruitment. Activation of muscles of one arm can activate homologous areas of the motor cortex on both sides of the brain, potentially leading to increased muscle recruitment in the affected arm. We used the Bimanual Arm Trainer (BAT, Mirrored Motion Works, Inc.) to connect the movement of the unaffected arm with that of the affected arm during shoulder external and internal rotation. Synchronized bimanual arm movement were followed by unimanual movements using the affected arm alone. Sixteen subjects with chronic post-stroke hemiparesis underwent EMG recording during unimanual shoulder external and internal rotation of the affected arm at baseline, after 6 weeks of usual care, and after 12 sessions with the BAT. External and internal rotation were chosen as these muscles are abnormally recruited post stroke. Muscle activity was recorded from the affected and unaffected arms using bipolar surface electrodes (DE 2.1; Delsys) from the following muscles: upper trapezius (UT), lower trapezius (LT), infraspinatus (INF), posterior deltoid (PD), triceps (TRI), biceps (BIC), latissimus dorsi (LD), and pectoralis major (PM). The EMG signals were preamplified and sampled at 2,000 Hz and normalized to the global maximum activity of each muscle for each subject. There was no significant difference in mean muscle activation in the unaffected arm between usual care and BAT training. Mean muscle activation in the affected arm improved in the infraspinatus, latissimus dorsi, pectoralis major, and upper trapezius following training with the BAT compared to usual care. The increased muscle activation correlated with increased active range of motion, and improved Fugl-Meyer scores in the affected arm after training with the BAT. The results suggest that bimanual to unimanual training with the BAT can improve muscle activation patterns post stroke.

Predicting reaching function in chronic stroke using loss of independent joint control, weakness, passive range of motion, and flexor spasticity during movement.

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Many factors may limit a chronic hemiparetic stroke survivor's ability to lift their affected arm against gravity and reach outwards toward an object. Possible underlying impairments affecting reaching function include weakness, loss of independent joint control (i.e., flexion synergy), flexor spasticity (i.e., hyperactive stretch reflexes), and passive range of motion limitations. The current study is using established kinematic/kinetic/electromyographic protocols to measure reaching function, single-joint strength, loss of independent joint control, and spasticity during voluntary reaching in the same cohort of chronic stroke survivors. The values will be entered into a multiple linear regression model to determine which factors best predict reaching function. A preliminary analysis of 15 chronic stroke survivors has been conducted. The cohort has an average age of 57.80 ± 12.03 years and is collectively 12.17 ± 6.85 years post-stroke. The average upper extremity Fugl-Meyer Motor Assessment score is 26.9 ± 7.88. Elbow extension and shoulder abduction strength were measured isometrically on both arms and the maximum voluntary torques are normalized to the unaffected side. The remaining protocols were completed in a customized robotic device including electromyography of elbow flexors and extensors. The affected arm rested in a forearm-hand orthosis as the participant viewed an avatar of the upper limb and virtual targets on a screen. Flexion synergy expression was measured using a binary decision tree to determine the maximum load at which the participant could lift the arm and produce sufficient elbow extension to reach a target that was near (i.e., the takeover threshold) to or far (i.e., the emergence threshold) from the body. The participants also completed center-out forward reaches under two loading conditions to measure both flexor spasticity and reaching function. Flexor spasticity during movement was defined as the increase in biceps electromyographic activity from reach onset to peak angular velocity at a standardized abduction load of 50% of maximum shoulder abduction strength. Reaching function was defined as the maximum reaching distance under normal gravitational loading. The interim regression analysis of 15 participants produced a significant result ($p = 0.013$), with the emergence threshold and spasticity already demonstrating correlations with reaching function, supporting continued investigation. More participants are necessary to ensure normal distributions of all regressors and significant correlations between each regressor and the regressand (reaching function) before the model may be appropriately applied.

Effects of early intensive hand rehabilitation on reorganization of bilateral motor topography following stroke are dependent on corticospinal tract integrity.

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Transcranial magnetic stimulation (TMS) induced motor evoked potentials (MEP) are an established proxy of corticospinal excitability. As a binary measure, the presence (MEP+) or absence (MEP-) of ipsilesional MEPs is a robust prognosticator of long-term recovery post-stroke, but does not provide information about cortical reorganization. To do so requires systematically acquiring MEPs to “map” motor topography. We tested the degree to which functional improvements resulting from early (<90 days post-stroke) intensive hand rehabilitation correlate with changes in ipsilesional topography, and compared contralesional topography changes between MEP+ and MEP- individuals. Following informed consent, 17 individuals (4F, 60.3±9.4 years, 24.6±24.0 days post first time stroke) received 2 weeks (7-8 sessions) of VR/Robotic training using the NJIT-RAVR system. Clinical tests [Box and Blocks Test (BBT), Wolf Motor Function Test (WMFT), Upper Extremity Fugl-Meyer Assessment (UEFMA)], kinematic assessments [Finger Range of Motion (f-ROM), Maximum Pinch Force (MPF)], and bilateral TMS mapping (150 stimulations, 110% of resting motor threshold) of the first dorsal interosseous (FDI) muscle were performed prior to (PRE), directly following (POST), and one month following (1M) training. Participants were divided into two groups (MEP+, MEP-) based on MEP presence in the affected FDI at any time point. A repeated measures ANOVA on MEP+ group ipsilesional FDI area revealed a significant effect of Time ($f(2,16)=7.84$, $p=.004$). Post-hoc comparisons indicated a significant increase between PRE and 1M ($t(8)=-3.37$, $p=.016$). A mixed factorial ANOVA on contralesional FDI area with factors Time (PRE, POST, 1M) and Group (MEP+, MEP-) indicated no significant main effects or interactions. The same ANOVA was applied to clinical and kinematic outcomes. Time X Group interactions were significant for the WMFT, BBT and f-ROM. MEP+ group improvement was significantly greater from PRE to 1M on the WMFT ($t(15) = -3.34$, $p = .005$), BBT ($t(15) = 2.72$, $p = .016$), and f-ROM ($t(15) = 2.86$, $p = .012$). PRE to 1M changes were correlated between FDI area and clinical/kinematic outcomes. MEP+ group ipsilesional FDI area was significantly correlated to WMFT ($r = -0.75$, $p = .017$), BBT ($r = 0.865$, $p =. 002$), and f-ROM ($r = 0.809$, $p = .008$, and contralesional FDI area was significantly correlated to UEFMA ($r = -0.840$, $p = .004$) and MPF ($r = 0.806$, $p = .008$). No significant correlations were found for the MEP- group. Early VR/Robotics training promoted significant recovery of hand function. Recovery was greater, and correlated with ipsi- and contralesional changes in motor topography for MEP+ individuals only.

The effect of early and intensive hand focused upper limb rehabilitation on recovery of long-term impairment.

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It has been proposed that impairment based recovery within the first 3-6 months post CVA is primarily dependent upon spontaneous biological recovery induced by the unique post-ischemic plasticity occurring during this time, and is not affected by dosage nor type of rehabilitation. Confirming this, 2 recent trials performed in the early period after stroke found that the rehabilitation dose did not affect outcomes,1 <>,2 <> but these studies offered a substantially smaller dose of rehabilitation than studies describing beneficial effects.3-5 <>In this study, we investigated whether an intense, hand focused Virtual Reality(VR)/Robotics based upper limb intervention introduced within the first month post-stroke resulted in greater than predicted recovery compared to that of a control group. Thirteen subjects [7 in the intervention group (VR) - 2F, 55.7±14 yrs, 11.9±8.9 days post CVA, and 6 in the usual care group (UC) - 2F, 62±10.8 yrs, 13.6±9.2 days post CVA] with first time stroke were included in this analysis. There was no statistical difference for days post CVA between groups. The 7 VR subjects received 8 – 1hr sessions of VR/Robotics training using the NJIT-RAVR system in addition to their inpatient therapy. The 6 UC subjects only received their inpatient therapy. All participants were tested prior to (PRE), immediately post (POST), 1 month post (1M), and 6 months post (6M) training on both clinical [Box and Blocks Test (BBT), Upper Extremity Fug-Meyer Assessment (UEFMA), Wolf Motor Function Test (WMFT)], and kinematic/kinetic tests [Finger Range of Motion (fROM), Maximum Pinch Force (MPF)]. A mixed ANOVA was conducted for all outcome variables with factors Time (PRE, POST, 1M, 6M) and Group (VR, UC). There were no significant differences between the 2 groups on all outcomes at PRE. Positive trends favoring the VR group were found for all outcomes. Specifically, there were significant main effects for TIME for all comparisons for the BBT, WMFT, fROM, and from PRE-6M for MPF. As well, there was a significant Group X Time interaction effect for the UEFMA [$F(1.89,20.79) = 3.59$, $p = .048$)] along with significant Time main effect comparisons at all levels in favor of the VR group. This significant between group difference in impairment-based recovery is reflected by a notable difference in observed versus predicted scores at 6M using the Proportional Recovery Rule 6 <>(VR: mean change of +3.3, UC: mean change of -8.3). These preliminary data suggest that intensive hand focused VR/robotics training introduced acutely may promote greater impairment based upper limb and hand recovery as compared to usual inpatient care post-stroke.

Interlimb differences during bimanual aiming after stroke: effect of target distance.

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Previous studies suggest that when the two hands move towards independent target goals, there is a strong tendency to synchronize movement times (Kelso, 1979). Do the two hands achieve this high degree of temporal synchrony by adopting similar movement trajectories? In this study, we examined the effect of manipulating target distance on movement time and directional error during bimanual aiming movements in non-disabled adults (ND) and chronic stroke survivors. Six right-hand dominant non-disabled young adults and 2 chronic stroke survivors – 1 left- (LHD) and 1 right-hemisphere damaged (RHD) – performed bimanual aiming movements to two visual targets in a frictionless 2D workspace, without vision of their hands. Visual feedback of hand position was not given during movements, but was available at the end of each trial. Additionally, performance feedback was given in the form of a numeric score. In 5 experimental conditions, target distance was manipulated symmetrically (6-6, 10-10, and 14-14 cm), and then asymmetrically (i.e., 6-10, 6-14 for the right hand, or, 10-6 and 14-6 for the left hand). We quantified movement time (T) and directional error at peak acceleration (DE-PA) and movement end (DE-ME) for the two hands and compared them across conditions in ND and stroke. Compared to ND, both LHD and RHD cases show a significant increase in T, DE-PA, and DE-ME (Wilcox $p < 0.0001$). We summarize and focus here on our findings for ND. First, as distance increases symmetrically (10-10, 14-14), ND showed a significant increase in T and DE-PA, especially for the farthest target (14-14 compared to 6-6), but only for the right hand ($p < 0.01$). DE-ME did not change across symmetric conditions. Second, for asymmetric-right conditions (6-10 and 6-14) T was longer for both hands ($p < 0.001$), and DE-PA were smaller but only for the right hand. Again, DE-ME did not change across asymmetric-right conditions. Third, for asymmetric-left conditions (10-6, 14-6), T was longer only for the left hand. As distance increased, DE-PA were smaller for the left hand, but larger for the right hand. DE-ME was significantly larger for the left hand ($p < 0.001$) but did not change for the right hand. Findings suggest that movement time synchrony is modified by target distance, particularly for the right hand. When present, such temporal synchrony is achieved through different movement trajectories by the two hands, as indicated by interlimb differences in directional error. Directional errors were also modified by target distance, and may provide insight into the locus of movement time asynchronies. Preliminary analyses of stroke cases suggest that bimanual movement deficits may differ between LHD and RHD.

Speed-accuracy relationships with motor learning post stroke.

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Robotic approaches to stroke rehabilitation provide the opportunity to explore fundamental biomechanical principles that can lead to better strategies to improve upper limb function. In this study we used a novel robotic Cable Driven Upper Arm Exoskeleton, CAREX, to determine the extent of motor learning on a 3-D circle drawing task with weight support and path assistance. Seven healthy subjects and nineteen subjects with chronic post stroke right hemiparesis participated in the study. Subjects were asked to follow a prescribed circular path with a constant diameter of 15 cm formed by 2 rods clamped on an adjacent stand providing 3 points through which to draw a 3-D circle at their preferred speed. Each subject performed 20 trials with CAREX under 3 conditions which were presented in a random order: (a) weight support alone, (b) path assistance alone, and (c) path assistance plus weight support. During the weight support conditions, the weight of the arm was estimated based on the height and weight of each subject. The upper limb Fugl-Meyer score (FMS) was used to classify subjects with stroke into low impairment (n=9, FMS=59.6±6.8) and high impairment (n=10, FMS=16.6±6.5) groups. Motor learning was assessed by changes in speed and accuracy. Accuracy was assessed by the normalized error, computed as the deviation area from a perfect circular path divided by the circumference of the actual trajectory of the 3-D circle drawn. Control subjects showed increased error at low and high speeds, but minimal error at 0.1±.025m/s. The low impairment group showed a similar pattern, but the optimal speed was lower at 0.075±.025m/s. The high impairment group showed lower error when they moved faster across the trials, i.e., the speed of circle drawing increased and the error decreased with learning. As expected, the mean error was smallest for the control group and not significantly different for the low impairment group. The error was significantly larger for the high impairment group, but the path assistance plus weight support condition showed significantly lower error and higher speed compared to the other conditions. The low impairment group was fastest with path assistance alone, whereas the control group was fastest with weight support. The results suggest that speed-accuracy relationships continue to improve in patients with severe chronic stroke with motor learning, and that weight support and path assistance have different effects in individuals with different degrees of motor impairment.

Quantifying nonlinear connectivity in the stretch reflex for chronic hemiparetic stroke in a pilot study.

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Unilateral brain injuries from a stroke can cause hyperactive stretch reflex activity. There is evidence that hyperactive stretch reflex activity is likely associated with an increased reliance on the reticulospinal system. We hypothesize that oligo-synaptic interactions via the corticoreticulospinal (CRST) system may increase the complexity of long-loop reflexive control, resulting in a more dominant nonlinear connectivity between stretch stimulation and muscle activity. Very recently, we proposed an advanced method for the assessment of nonlinear connectivity and its time delay that cannot be exploited by linear coherence approaches. In this study, we applied our nonlinear analysis method to investigate nonlinear connectivity in the stretch reflex of individuals with chronic hemiparetic stroke. We recruited three participants with chronic hemiparetic stroke and two age-matched healthy controls. A multi-sine wave continuous perturbation was applied to the elbow joint while stroke participants performed shoulder abduction (SABD) tasks using their paretic arms, at the level of 0% (arm supported), 20% and 40% of their maximum SABD voluntary torques. Stroke-induced synergetic elbow flexion torques were averaged across the 3 stroke participants, separately at 20% and 40% SABD levels. Then in healthy controls, the same elbow perturbation was applied to the dominant arm while they generated SABD and elbow flexion torques at the level that matched the synergetic elbow flexion in stroke subjects. EMG activity of elbow flexors (i.e. brachioradialis, biceps brachii) of the tested arm were recorded. The nonlinear connectivity between the perturbation and EMG were calculated using our nonlinear method. The time delay was estimated based on the relative phase between the continuous perturbation and EMG, which is influenced by both spinal and supraspinal loops. We found that stroke subjects show increased nonlinear connectivity and prolonged time delay as compared to healthy controls. Furthermore, nonlinear connectivity and time delay increase with synergic elbow flexion (associated with SABD levels) in only stroke subjects. As spinal reflex latency would not change after stroke, the prolonged delay is likely related to supraspinal reflex contributions. Increased nonlinear connectivity and delay may be originated from the CRST, since higher SABD level increases the usage of CRST in stroke subjects. This study, for the first time, provides evidence of changes of nonlinear connectivity in the stretch reflex after hemiparetic stroke, indicating that nonlinear analysis may provide new insights into abnormal stretch reflex activity caused by a stroke.

A Machine Learning Approach for the Quantitative Assessment of the Upper Extremity Movement in Stroke Survivors.

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Standardizing the quantitative evaluation of movement among stroke survivors can improve monitoring of therapy progress and customization of therapy. To achieve this goal, evaluating movement during therapy and activities of daily living (ADL) is important. Semi-automated evaluation (through a cyber-system with supervision by an expert therapist) can support interactive home-based rehabilitation and instrumented capture and assessment of activities of daily living. Semi-automated assessment of upper extremity activity requires capturing information on the hand, entire upper limb as well as torso movement. This capture must be assessed in the context of goal oriented movements in relation to various objects. Accelerometry-based sensing of limbs lacks activity context. Unobtrusive monitoring of the digits is also a major challenge. Therefore, our team focuses on marker-less computer vision solutions. While our previous work was based on integrated analysis of core kinematic elements, our present studies explore a machine learning approach that is more scalable and robust.

Our current approach integrates the following components: Development of an array of training tasks and related custom objects that can generalize to many ADLs. Development of a common vocabulary of operationally-defined movement segments that are applicable to all training tasks. These segments are labeled as: Initiation, Progression, Termination, Transportation and Manipulation, Complex Manipulation or Bimanual Manipulation, Release and Return. Development of a rating protocol that identifies three key movement parameters to be monitored per segment maps the assessment of these parameters to a rating score between 1 and 3 per segment maps the rating of the segments to an overall rating score of the task between 1 and 3, video capture of task performance by stroke survivors having different impairment profiles, segmentation of captured tasks, development of an interactive online platform that allows therapists to rate the segments and the tasks, analysis of the ratings for consistency and improving the rating protocol

Future work includes: Using the collected ratings to train machine learning algorithms for automated rating of tasks and segments. We will apply representation learning approaches to capture latent factors that may have escaped our rating protocol. We will use the results to further improve the rating protocol and algorithms.

Integrating prediction from visual inputs with accelerometry and smart skin measurements to further refine the system.

Applying the improved system for semi-automated home based therapy and rating of ADLs.

A novel robotic device for shoulder rehabilitation.

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The current work presents a novel kinematic mechanism for a robotic device to train shoulder movements in people suffering from neurological injuries such as stroke. The developed mechanism reduces the structural complexity of the robot and makes it more ergonomic.

The use of robots for physical rehabilitation has been shown to be effective over the past two decades, during which the field has seen increasingly complex robots with high dof (degree of freedom) aimed at functional rehabilitation of the arm. Many existing exoskeleton arm robots are large and heavy, with complex mechanisms [1]. Conventionally, they require the user to be well-aligned with the robot, imposing position and orientation constraints on the user [2]. This makes the device un-ergonomic, and in extreme cases, can cause unconstrained forces on the arm if the arm is not aligned properly with the exoskeleton. Therapy can be made easier by making the robots lighter, simpler, more ergonomic and portable.

We have designed an arm movement training robot that does not require the user to be spatially aligned with respect to the robot. The Arm Rehabilitation Robot (AREBO) is a 2 dof pneumatically actuated robot, which can be used to train 3D arm movements against gravity. It uses a novel kinematic mechanism to connect the robot and the human arm by a passive linkage, to avoid unconstrained forces on the arm. Such a mechanism essentially decouples the robot and the user, eliminating the need for robot and human joint axis alignment. This design saves the time and effort needed to align the user with the robot, and also waives the need to include constraint-imposing elements in the robot, making it structurally simpler. A calibration algorithm has been developed for the robot to automatically estimate the user's shoulder joint position, and appropriately control the human arm. The proposed mechanism and the calibration procedure can improve the device's ease of use and provide better physical human-robot interaction. In this paper/poster, we present the design aspects of AREBO, its forward and inverse kinematics, and the calibration procedure for shoulder position estimation.

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Refining movement quantitation in stroke.

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Functional training is the mainstay of rehabilitation after stroke, but no measurement tool exists to objectively quantify functional movements in the upper extremities (UE). In previous work, we classified (i.e., automatically identified) components of functional movements using a combination of wearable inertial measurement units (IMUs) and a machine learning (ML) algorithm. Although classification performance was encouraging, this approach had computational limitations, such as ML training time. It also had practical limitations, such as cost and magnetic drift. In this study, we sought to refine this approach to optimize motion capture and analysis in stroke patients. We determined the ML algorithms, sensor configurations, and data requirements needed to maximize accuracy and practicality.

Data were collected from 6 mild-to-moderately impaired stroke patients moving objects on a horizontal target array. Patients wore 11 IMUs on their upper body (hands, forearms, arms, shoulders, T8, head, and pelvis). To optimize computational performance, we evaluated 4 ML algorithms (naïve Bayes, support vector machine, linear discriminant analysis (LDA), and K nearest neighbors). We compared their classification accuracy, computational complexity, and tuning requirements. To identify optimal sensor configurations, we progressively sampled fewer sensors using domain knowledge and exhaustive search, and compared classification accuracy. To identify optimal data requirements, we compared classification accuracy using data from IMUs vs accelerometers.

We found that LDA had the highest accuracy (positive predictive value (PPV) 92%) and pragmatism (ML training time (23 min); ML testing time (0.28 ms); 3 tuning parameters) of the 4 algorithms. We found that 7 sensors (paretic hand, arm, shoulder, head, pelvis, and T8) resulted in the best accuracy (PPV 92%). Poorer accuracy was found with 11 sensors (PPV 89%), or fewer sensors (hand-forearm-arm (PPV 81%); forearm only (PPV 71%)). Using the 7 sensors, accelerometry data had a lower accuracy (PPV 84%) than IMU data.

Overall, we refined strategies to accurately and pragmatically quantify functional movements in stroke patients. Among several ML algorithms, LDA represented the best balance of accuracy and practicality. We also found that more or fewer sensors are not better for improving accuracy, and that an optimal configuration captures motion only in the moving limb and trunk. Finally, accelerometry, having fewer dimensions, had poorer accuracy than IMU data. However, if constrained by expense and magnetically noisy environment, accelerometers may be sufficient for UE movement identification.

Does the relationship of impairment to function differ in stroke patients with excellent vs. limited upper-extremity motor outcomes?

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Background and Purpose: Motor outcomes for the upper extremity after stroke vary depending upon whether they are measured in terms of function (e.g. with the Action Research Arm Test, ARAT) or impairment (e.g. with the Upper-Extremity Fugl-Meyer, UE-FM). The relationship of impairment to function remains unclear and may vary in patients with differing functional outcomes. Functional outcomes for the upper extremity at 3 months post-stroke can be predicted within the first 72h after stroke using the PREP2 algorithm. Here we investigate the relationship of function to impairment, and whether this relationship differs across PREP2 categories for 'Excellent', 'Good', 'Limited' or 'Poor' outcomes. Methods: A retrospective analysis of data pooled from two previous studies of 207 stroke patients was completed (median age 72, range 18 – 98 years), and Spearman's rho was calculated for the 12-week ARAT and UE-FM scores within each of the four PREP2 outcome categories. A regression line was also fitted to the data for each outcome category. Results: The relationship between function (ARAT) and impairment (UE-FM) at 12 weeks post-stroke differs among the PREP2 outcome categories. Function and impairment are most strongly correlated in the Limited outcome group, but the strength of this relationship progressively weakens in the Good and Excellent outcome groups. Similarly, the adjusted R2 values are highest for the Limited outcome group, with impairment accounting for less of the variance in function in the Good and Excellent groups. Conclusions: The relationship of function to impairment differs across PREP2 outcome categories and this should be considered when tailoring the therapy focus on reducing impairment or restoring function.

Methodology to estimate voluntary activation of the paretic elbow and wrist muscles in chronic hemiparetic stroke using twitch interpolation.

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Paresis, a decrease in the voluntary activation of muscles, causes weakness, and makes it difficult for stroke survivors to complete activities of daily living. The amount of paresis that occurs at specific joints in the upper extremity has not been quantified. This paper will describe the methodology and preliminary results for using twitch interpolation to quantify the ability to activate the elbow and wrist flexors and extensors in the upper limb post chronic hemiparetic stroke. Voluntary activation of the elbow and wrist flexors and extensors was assessed in both limbs of two individuals post stroke. A 6 degree-of-freedom load cell was used to measure elbow torque while a single axis torque sensor was used to measure wrist torque. A standard twitch interpolation protocol2 was modified to optimize measurement of the paretic upper extremity. A bipolar stimulation setup was used with one electrode over the motor point (cathode) and one electrode distal to the motor point (anode) and a single monophasic pulse was used with duration of 100μs. Maximal stimulation amplitude was set at the amplitude where the measured joint torque plateaued or began to decrease. Participants were asked to relax followed by a maximum voluntary contraction (MVC). A stimulus of maximal amplitude was applied during the MVC. A second stimulus was applied after the first stimulus, with the limb back at rest. This was repeated for 6 trials. Voluntary activation was estimated using the following formula: Voluntary Activation = [1-(twitch torque/resting twitch torque)]1100%, where twitch torque represents the torque produced by electrical stimulation during MVC and resting twitch torque represents the torque produced by electrical stimulation with the limb at rest.

RESULTS: Preliminary results show decreased ability to activate muscle groups in the paretic, compared to the non-paretic upper limb. Average voluntary activation of the non-paretic and paretic limb was 96% and 62% for the elbow flexors, 94% and 82% for the elbow extensors, 92% and 52% for the wrist flexors and 90% and 33% for the wrist extensors, respectively. Voluntary activation of the wrist muscles appears to be less than the elbow muscles, however, conclusions must be made cautiously due to small sample size.

DISCUSSION: This study shows that it is feasible to quantify voluntary activation of the elbow and wrist flexors and extensors in individuals with chronic hemiparetic stroke and describes methods to do so. The use of the twitch interpolation method to quantify deficits in voluntary activation in the paretic upper extremity of stroke subjects will help us determine differences between proximal and distal muscles.

Quantification of relative arm use using inertial measurement units: device design and pilot study.

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Neurological conditions such as stroke often lead to unilateral sensorimotor impairments. Thus stroke patients often use their less affected side more than the affected side. Quantitative assessment of a patient's relative arm use is essential to provide effective therapy for countering this condition. Majority of the current assessment methods of relative arm use, performed in a clinical or laboratory setting, are prone to reporter bias and may lack ecological validity [1]. Also, though these measures are good indicators of motor capability they are only partial indicators of the actual amount of use of the paretic limb in the natural setting. In this study, we extend the work of Leuenberger et al. [2] to develop and validate a method for estimating relative arm use in an ecologically valid setting using a pair of wrist-worn inertial measurement units (IMUs). Here, we present the design of an IMU-based wearable device (IMU-Watch) and a pilot study to evaluate the feasibility of using the IMU-Watch for home-based assessment of relative arm use. A wrist-watch like wearable sensor has been developed for recording movements of the two arms during daily life. The pilot feasibility study is conducted on five chronic stroke patients with mild-moderate hemiparesis, and an equal number of age and hand dominance matched healthy controls. After providing informed consent, stroke subjects undergo the FMA, AAUT and MAL assessments. Following this, they wear the IMU-watch for one week throughout their waking hours (except when the watch can be damaged due to water). At the end of the week, data from the IMUs is used to estimate the amount of use of the two arms. This arm use data is summarized as the relative use of the two arms for each of the seven days of the study duration. The data is also used to identify the minimum number of days the watch should be worn to get an estimate of habitual arm use. Exploratory data analysis is performed to compare the newly developed measure of relative arm use and standard laboratory tests for arm use (AAUT and MAL).

Reference:

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Volitional muscle activation restores elevated motoneuron excitability following multiple stretches in chronic hemiparetic stroke.

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Purpose: Spasticity is a prevalent motor impairment afflicting ~40% of individuals with chronic stroke. It is defined as a hyperactive stretch reflex and results from an increase in spinal motoneuron excitability following stroke, making muscles more resistant to stretch. Spasticity is commonly treated by repeated passive stretches of the paretic limb, which research has confirmed results in a decrease in abnormal stretch reflex torque. However, the longevity of this stretch-induced reduction is unknown yet has great implications on the efficacy of stretching as a spasticity-reducing tool.

Methods: Eighteen participants with chronic hemiparetic stroke had their forearm casted and affixed to a robotic device that measures torque and positional data. The robotic device stretched each participant's forearm about the elbow joint through extension and flexion between 70° and 150°. The participant's forearm was first stretched 20 times at 120°/s, then the participant volitionally activated their arm musculature by producing five ballistic extension-flexion movements, and finally the participant's forearm was stretched again 20 times at 120°/s.

Results: The first set of stretches at 120°/s significantly reduced the abnormal biceps stretch reflex torque. However, the biceps stretch reflex torque returned to a magnitude that was slightly greater than the initial, pre-stretching magnitude after five volitional ballistic movements. The second set of stretches also significantly reduced the abnormal biceps stretch reflex torque, similarly to the first set of stretches. For both sets, accommodation of the biceps stretch reflex occurred primarily within the first three stretches, and then greatly decreased in the remaining seventeen stretches.

Conclusions: Repeated stretching that evokes the hyperactive stretch reflex appears to decrease motoneuron excitability, thus, decreasing stretch reflex activation post-stroke. Volitional muscle activation, however, is likely to restore elevated motoneuron excitability and hyperreflexivity. This evidence suggests that the therapeutic effect of stretching is not long lasting, and particularly lacks robustness to volitional movement. Thus, the time and money invested in stretching to relieve spasticity in the clinical setting may be negated the moment the patient voluntarily moves.

Manual dexterity in grasping and manipulation for patients with upper limb hemiparesis after stroke.

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The effects of a stroke can lead to difficulties in motor planning, muscular control and/or sensory feedback, thereby causing limitations to upper limb coordination. Exactly how these different changes affect manual dexterity during hand-object interactions remains unclear. This study examines the grasping and manipulation abilities of ten patients suffering from hemiparesis post stroke in order to characterize hand function deficits. Following standardized clinical testing, a handheld device with an integrated inertial motion unit and multiple force sensors was used to evaluate grip forces, object orientation and acceleration. Each individual completed a series of tasks involving several grasp configurations and a series of basic actions including turning the device, in-hand rotation and pretending to drink from a glass. Performance of the affected and non-affected sides were compared across the different phases of each movement (loading, lifting, holding / manipulation, unloading). Using specific examples, we show how particular sensory and motor deficits contribute to problems with motor planning, grip force scaling and object handling according. Through our ongoing work we seek to classify these dexterous handing issues in order to determine effective clinical management strategies for improving neuromotor control and manual dexterity of patients suffering from stroke.

Increased training frequency leads to improved arm motor outcome with bimanual-to-unimanual training post stroke.

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Few options exist for training arm movements in patients who have limited movement in their arm post stroke. Movement on one side of the body activates homologous cortical areas in both hemispheres. Coupled bimanual movements have been shown to prime the contralesional motor cortex for subsequent movements with the affected arm post stroke. Therefore, we designed a bimanual-to-unimanual training protocol where bimanual arm training is followed by unimanual training of the affected arm. Our goal was to explore the effect of training dose of bimanual-to–unimanual on motor improvement. 20 subjects with chronic post-stroke hemiparesis underwent 6 weeks of usual care. They then received 12 one-hour sessions of bimanual-to-unimanual training using the Bimanual Arm Trainer (BAT, Mirrored Motion Works, Inc.). Some patients received the 12 sessions three times a week over 4 weeks, whereas others received it twice a week over the course of 6 weeks. Arm motor outcome was assessed using the upper limb Fugl-Meyer Scale and active range of motion at upper limb joints at baseline and then pre- and post-training with the BAT. Significant improvement in the Fugl-Meyer scores and active movement was noted after training with the BAT compared with after usual care. The difference was significantly greater in patients who underwent three sessions of training per week compared with those who underwent training twice a week. Higher frequency of training leads to greater motor improvement despite the same total dose. The study provides a means for understanding dosing of treatment for motor learning post stroke.

Development of adaptive mechatronic guitar for stroke rehabilitation.

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Stroke frequently leads to persistent sensorimotor impairments and reduced upper extremity function. A promising novel rehabilitation technique relies on training post-stroke individuals to play musical instruments to improve upper limb function. This complex task requires precise spatio-temporal coordination of movements, inducing neuroplasticity and auditory-motor network coupling in healthy and neurologic populations (Herholz & Zatorre, 2012). Previous studies showed that short-term music-supported therapy using piano and electric drum kit leads to clinically significant improvements in fine and gross motor function with respect to speed, precision, and smoothness (Schneider et al., 2010) as well as measurable increases in bilateral activation of sensorimotor cortex and increased excitability of the primary motor cortex of the affected hemisphere (Ripoles et al., 2016; Rojo et al., 2011).

One gap in the current music-supported interventions remains the accessibility of musical instruments to individuals with different levels of arm/hand impairment. To fill this gap, we developed a mechatronic chord actuation system (MechaTar) that allows playing acoustic guitar without manually fretting chords. The device consists of a servo-controlled mechanism positioned on the fretboard to actuate the chords, a set of switches to trigger chord changes, and a graphical user interface. Any chord on the first four frets could be programmed. Depending on the degree of arm/hand impairment, MechaTar can be used as a form of constraint induced therapy where the paretic arm performs rhythmic strumming, while the non-paretic side (foot or hand) is used to press the pedals to change chords. Alternatively, practice can be structured as a form of bilateral training where the non-paretic arm is used for strumming, while the paretic arm is used for chord switching and the foot can also be used in cases of more severe arm impairment. In all these cases, there is a requirement for precise coordination of rhythmic and discrete movements of the upper extremity, which form two basic classes of movements controlled by the CNS (Hogan & Sternad, 2012) as well as action selection. We hypothesize that multi-day training with MechaTar will improve gross and fine motor function of the paretic arm, increase bimanual coordination, and improve quality of life in individuals recovering from stroke.

We are currently piloting the device with stroke victims with different levels of upper limb function and impairment with the goal of creating an appropriate task difficulty levels. We expect to present these preliminary data and the technical characteristics of the device at the conference.

Primary motor cortical activity patterns during post-stroke hand movements of increasing demand.

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After stroke, patients with impaired hand function usually exhibit abnormally high activity in ipsilateral primary motor cortex (M1ipsi) during movement of their affected hand. One explanation for this increase is that M1ipsi reorganizes as a response to injury to the motor output system of the contralateral hemisphere. However, evidence from healthy subjects and patients showing a parametric increase in M1ipsi activity with greater motor demand suggests that abnormal M1ipsi activity after stroke stems from reduced efficiency in the neural circuitry. To distinguish between these alternative possibilities, we measured movement kinematics and functional magnetic resonance imaging (fMRI) activity during unimanual performance of a task that varied in the demand on accuracy. The demand hypothesis predicts M1ipsi would be related to varying demand, but scaled differently in patients and controls. In contrast, reorganization of M1ipsi may lead to a disrupted relationship between neural activity and demand in patients. Subacute stroke patients (N = 14, affected hand) and healthy controls (N = 17, right and left hands) manipulated an MRI-compatible joystick to move a small cursor into a target in one of four possible locations. The level of motor demand was varied by changing the target size (small, medium, large, extra-large) across blocks of four movement trials. EMG activity of the extensor carpi ulnaris muscle was used to verify absence of movement of the non-moving hand. Despite global deficits in task performance, stroke patients showed demand-dependent motor behavior similar to the healthy controls. A region-of-interest analysis in M1ipsi showed small demand-dependent increases that were similar in both groups, suggesting recruitment is in part related to task demand. Representational similarity analysis of the multivoxel patterns within M1ipsi revealed evidence for distinct activity patterns for movements of different target sizes in healthy subjects, such that patterns during the small movement blocks were most similar to the medium blocks and least similar to the extra-large target blocks. In patients, M1ipsi similarity patterns showed less variation with demand, and correlated less strongly with models of kinematic performance. These results suggest that reorganizational processes after stroke may alter the underlying neural representations for movement.

Load-dependent reliance on the ipsilateral hemisphere results in limited hand opening in moderate to severe chronic stroke.

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Hand function, particularly opening, is often significantly impaired following stroke, especially in moderate to severely impaired individuals. Unfortunately, lifting the arm, a crucial component of many activities of daily living, usually further reduces hand opening ability in this population, often even inducing involuntary closing. This is a consequence of involuntary abnormal coupling between the shoulder abductors, elbow, wrist, and finger flexors termed the “flexion synergy”. This lifting-induced hand impairment is hypothesized to be due to insufficient drive from contralateral corticofugal pathways following the stroke and compensatory reliance on ipsilateral corticobulbar pathways. In support of this, our lab previously showed that lifting against progressively heavier loads led to increased reliance on the ipsilateral hemisphere and decreased reaching ability in stroke, but not controls. However, whether this remains true for the hand remains unclear.

To fill the above gap, we recruited 14 individuals with moderate to severe chronic hemiparetic stroke and 6 healthy age-matched controls. Individuals participated in a high-density EEG experiment in which they performed 2 tasks on an ACT3D robot: 1. Hand opening and 2. Hand opening while lifting against 50% maximum shoulder abduction (SABD) force, using the paretic (stroke) or dominant (control) hand. We then quantified the following for both tasks: 1. A laterality index (LI) which reflects the relative contribution of the contralateral and ipsilateral sensorimotor cortices; 2. A Cortical Activity Ratio (CAR) for primary sensorimotor and secondary motor regions which reflects the relative strength of one region of interest compared to the entire sensorimotor cortex.

Individuals with stroke demonstrated an increased functional reliance on the ipsilateral (contralesional) hemisphere compared to controls during attempted hand opening. Furthermore, the addition of lifting caused an even greater reliance on the ipsilateral hemisphere in stroke, but not controls. This was driven by a decrease in activity in contralateral primary sensorimotor cortex and an increase in activity in ipsilateral secondary motor areas. These findings suggest that individuals with stroke dynamically depend on the ipsilateral hemisphere as the demand (i.e., load) of the task increases, which may underlie the observed flexion synergy impairment of the arm and hand.

Alternate hand training facilitates tactile adaptation post stroke.

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Effective hand function requires the integration of sensory information with motor output. Tactile information is necessary to prevent slippage of the object and adapt the fingertip grip forces to the frictional surface such that smoother surfaces elicit higher grip force rates than rougher surfaces. Patients with hemiparesis have difficulty adjusting their grip forces to manipulate everyday objects, which negatively affects their quality of life. The purpose of this study was to determine the extent to which tactile and kinesthetic information from the unaffected hand and visual information can be used to improve grip force adaptation to various textures and performance on a grasp-and-lift task. Forty patients with post stroke hemiparesis performed a grasp-and-lift task under eight different learning conditions, each involving a different combination of tactile, kinesthetic and visual cues. Each patient practiced the task with the affected hand only in one session and then by alternating the unaffected and affected hands in a subsequent session. A rank-based clustering algorithm was used to delineate statistically significant patient subgroups, who demonstrated condition-specific changes in performance. These subgroups corresponded to a "tricluster" consisting of a subset of patients, sensory conditions and grip task outcome measures that responded to alternate hand training. The results suggest that alternate hand training may facilitate the use of tactile and kinesthetic information from the unaffected hand to improve grasp control in the affected hand post stroke. Patients with different degrees of motor and sensory impairment require different training regimens.

Target uncertainty affects the reaching movements performed in standing by stroke survivors.

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Stroke individuals have reduced capacity to maintain the balance in the upright standing which can affect the execution of many activities of daily living. They also present several changes in their ar <>m movements in sitting position that should be more evident in standing position. The arm reaching movements performed in standing require anticipatory postural adjustments based on the characteristics of the voluntary movements such as the target location to be reached. Therefore, the current study examined the arm movement and postural sway when stroke survivors reached a target under the certainty (i.e., participant had prior knowledge of the final position of the target) and uncertainty (i.e., the target location was uncertain as it could change after the beginning of the movement) conditions in the final target location. The reaches performed by the individuals who suffered a stroke (n=12) using their ipsilesional arm were compared with the movements of healthy controls (n=12). The target was presented on a monitor screen placed at a distance of 105% of the arm length in one of three heights, at the eye level (center target) or 10 cm superior or inferior to the center target. Participants stood with a foot in each force plate. Neuromotor variables (onset movement time, movement time and accuracy), angular displacements of the ipsilesional upper and lower limbs, linear displacement of the trunk, center of pressure displacements of each limb and resultant and percentage of weight bearing in ipsilesional limb were analyzed. Stroke individuals took more time to start their movements, were slower and asymmetrical compared to the healthy controls. The angular displacements and center of pressure increased with target uncertainty for both groups. The accuracy of the reaches was similar for both groups and conditions. These results suggested that the central nervous system can modulate the reaching movements and the postural adjustments in relation to the uncertainty in the final target position to be reached and independent of the stroke occurrence. The findings of the present study contribute to the understanding of motor control in the upright position and the alterations in the movement characteristics. These implications should be considered in the rehabilitation of reaching movements and balance of stroke individuals.

Reaching movements in upright posture: use of motor abundance is affected by uncertainty in target location.

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The performance of the arm reaching in standing requires adequate control of hand trajectory and body stabilization to reach the target without having a fall. Several joint combinations can be used to successfully reach the target location while the balance is maintained. It is still unclear how the use of this motor abundance is affected when the target location is uncertainty, which requires mostly changes in the motor planning. Therefore, the present study examined the use of motor abundance to perform reaching movements and postural adjustments when there was uncertainty in the final target position to be reached in standing. Ten young adults stood on two force platforms and reached one of the targets presented on a monitor screen placed at three different heights (a center target at the eye level or 10 cm upper or 10 cm lower to the center target). The monitor was placed at a distance of 115% of the upper limb's length. Participants performed the reaches under two task conditions defined by prior knowledge (certainty) or not (uncertainty) of the target's final height. Kinematics of the body segments and resultant center of pressure displacements in anteroposterior direction (COP_{AP}) were recorded. The use of motor abundance was computed using Uncontrolled Manifold (UCM) approach relating the joint angles to two performance variables, the stabilization of the resultant hand's position or COP_{AP} position. The analyses included joints of the upper (scapula, shoulder, elbow, wrist) and lower (pelvis, hip, knee, and ankle) limbs. The variance components affecting (V_{ORT}) or not (V_{UCM}) the performance variables were compared between conditions. The V_{UCM} was always greater than V_{ORT}, regardless of the performance variable to be stabilized. The uncertainty affected only the joint combinations related to the stability of the COP_{AP} position. These results indicated an increase in the use of motor abundance with target uncertainty on the COP stabilization. The fact that more motor flexibility was used to stabilize the COP with target uncertainty and not the hand's position, it may indicate a neural strategy to maintain the same hand trajectory to reach the target. These findings could contribute to the understanding of the strategies used by the neurologic patients performing similar tasks.

Reliability of outcomes computed within the uncontrolled manifold (UCM) framework and clinical implications.

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Many methods to estimate the stability of action for multi-element systems have been developed within the uncontrolled manifold (UCM) hypothesis framework. A method quantifies inter-trial variance within a space where a salient performance variable remains unchanged (VUCM) and within an orthogonal space (ORT), where the performance variable does change (VORT). Another computes displacements within the UCM (motor equivalent, ME) and ORT spaces (non-motor equivalent, nME) in quick actions or reactions. Yet, a new method quantifies the stability of hand force production in the space of control variables; referent coordinate (RC, changed by the so-called r-command) for the hand and its apparent stiffness (k, changed by the so-called c-command). In this study we explored the reliability of several outcomes used in UCM studies during a four-finger accurate force production task. Fourteen young adults performed the accurate force production task with each hand on three days. Small spatial finger perturbations were generated by the "inverse piano" device three times per trial (lifting the fingers 1 cm/0.5 s and lowering them). The data were analyzed using: 1) computation of indices of the structure of inter-trial variance (VUCM, VORT, and the synergy index ΔVZ) and motor equivalence (ME and nME) in the space of finger forces, and 2) analysis of RC and k values for the hand and the synergy index (RSD and R2 of the hyperbolic relationship between RC and k). Results showed that VUCM and the ME dropped over the trial duration, but not across days, and showed good to excellent reliability. VORT and nME dropped over the three days and showed poor to moderate reliability. The correlations between √(VUCM) and ME for both hands were significant and moderate. Similarly, the correlations between √(VORT) and nME ranged from moderate to strong. Also, results revealed relatively poor reliability in outcome variables reflecting action stability (ΔVZ and RSD), however, that showed no significant changes over the three days. RC and k co-varied strongly and both showed good reliability. However, the computed index of force stabilization obtained from RC and k data set showed poor reliability. Our findings suggest that indices of ME show, on average, better reliability VUCM. Given the correlation between the sets of outcome variables, ME indices have an advantage and may be recommended for applied studies of synergic control. With respect to analysis of synergies in the space of hypothetical control variables, both RC and k showed good reliability, but their indices of synergy may not recommended due to their poor reliability.

Grip and load force coordination in an oscillatory manipulation task in diabetic individuals with and without peripheral diabetic neuropathy

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The peripheral diabetic neuropathy (DPN) affects the sensory and motor function of the upper and lower extremities. We had recently observed that individuals with diabetes mellitus (DM) with and without diagnosed DPN applied lower grip force (GF) than healthy individuals when they were asked to hold an object. However, it is unknown if this lower GF shown by diabetic individuals would also be observed during a manipulation task in which cyclical changes of the tangential/load force (LF) occurs. It is known that the directional and temporal coupling between GF-LF are altered in some central and peripheral neurological diseases and may, therefore, be changed in diabetic individuals with and without DPN. Thus, we aimed with this study to examine the effect of DPN on the GF control and the GF-LF coordination during a cyclical manipulation task with a free moving object. We evaluated 36 individuals separated in three groups: individuals with DM without DPN (DM), individuals with DM with DPN and healthy controls, all matched by age and sex. To perform the oscillation task, they had to hold an instrumented handle with force sensors using the tip of the five digits of their dominant hand and continuously move the object vertically up and downward by 20 cm at 1 Hz. The dependent variables were (i) the safety margin (SM) calculated using the averaged GF during the oscillation task (GFmean), and the minimum GF needed to hold the object (GFmin), [SM=((GFmean-GFmin)/GFmin)*100], (ii) the maximum value of the cross-correlation coefficient (rMax) and (iii) the time-lag. No statistical differences between groups were found for any dependent variables analyzed. Based on these findings we conclude that the DM and DPN do not affect the GF control and coordination between GF-LF during an oscillation task. Coordination between forces is preserved because brain structures (e.g., cerebellum) responsible for GF-LF coordination might be preserved in individuals with DM with and without neuropathy. The GF control was also not affected by this task, probably due to the intense inflow of the tactile sensory information originated from the mechanoreceptors of the fingertips caused by the cyclical change in LF. This strong inflow of tactile stimuli would be sufficient to provide accurate information about the change in the relation between the digits skin and the object surface to the central controller, which would, therefore, be able to adequately control the amount of GF needed to perform this task.

Key-words: diabetes mellitus, force control, mechanoreceptors

How many trials are needed to obtain reliable estimates of multi-finger synergies?

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ABSTRACT

Stability of performance variables during multi-finger force production hand task has been quantified across multiple trials (around two dozen) using the framework of the uncontrolled manifold (UCM) hypothesis. Recent analyses of stability of performance in multi-element tasks showed high sensitivity to subcortical disorders and subclinical conditions. However, collecting multiple trials to obtain sufficient clouds of data points may be impossible for certain populations. The main purpose of this study was to compare three methods with respect to their ability to provide reliable estimates of the corresponding stability indices based on relatively few trials. The three methods (inter-trials variance, motor equivalent computed in single-trials but averaged across trials, and analysis of {RC; k} pairs across trials) were applied to the same dataset collected in a very simple task of four-finger accurate force production. Fourteen healthy, young adults performed multi-finger force production task on three different days. The minimal number of trials was obtained by three different methods. All three methods revealed that around 15 trials were needed to find stable indices of the structure of variance and motor equivalence. The current findings suggest that a small number of trials than usually is used can be recommended for the analysis of the multi-finger force production task. Clinical studies can take advantage of the specific recommendation about the number of trials for each analysis, reducing the total duration of the experiment.

Fingertip force distribution changes as a function of thumb stability.

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The thumb plays a significant role in any prehension task. In this study, we focused on the changes in fingertip forces when as we selectively changed the vertical stability of the thumb. We used a custom handle consisting of four ATI Nano17 sensors for the index, middle, ring and little fingers spaced equally apart (20 mm); and a Nano17 sensor mounted on a moving rail platform for the thumb. This allowed relatively friction-free vertical movement of the thumb sensor along the rail. The mass of the entire handle was approximately 0.535 kg. The mass of the moving platform (below the thumb) was 0.165 kg. We used a liberty electromagnetic tracking sensor (Polhemus, USA) to measure position and orientation of the handle. Further, since the position of the thumb could change due to changes in vertical tangential force applied by the thumb, we used a Laser displacement sensor to measure the displacement of the thumb sensor.

Sixteen right-handed, young healthy male volunteers (Age 25.66±2.69 years) participated in the experiment. The experiment consisted of two conditions (blocks), each consisting of 30 trials, each trial lasting 10s. In the experimental task, the participants lifted the handle and were instructed to support the handle weight by applying minimum grip force. During the task, the handle has to be maintained in static equilibrium without tilting. In one condition, the thumb sensor slider is fixed at a position between the middle and the ring finger using a screw, while in the other condition, the slider was free to move with the screw released. Participants were required to maintain the slider between the middle and ring finger. An error margin of ±5mm from a marked position between ring was allowed. The order of conditions was balanced across subjects. There was a rest of 30s between trials. Each block of the experiment was conducted in a separate session, the two sessions separated by a minimum of 60 minutes. Data was collected at 100Hz using LabVIEW.

Results: Subjects used different strategies in the two conditions. In the case where the thumb sensor was fixed, the average thumb grip force was ~6N whereas when the thumb freely moved vertically, it was ~10N. Synergy indices were different between the two conditions. In particular, it was found that the little and ring finger normal forces compensated for the reduction in the thumb tangential forces. We explain and discuss the results using the well-documented principles of superposition and adjustments of synergies using chain effects.

Interpersonal synergies: a highly unstable, dynamical task performed by two actors.

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When a person executes a motor task alone, redundant sets of elements within the body are organized by the central nervous system into synergies stabilizing the task (Latash et al. 2008). Our previous studies showed that visual feedback (Solnik et al. 2015) and haptic information (Solnik et al. 2016) are sufficient for the organization of synergies when two persons are involved in a motor task. These studies also showed that in a task with physical constraints, synergies were larger when task was performed by one person, suggesting the significant role of the haptic and proprioceptive systems. It is not clear, however, if interpersonal synergies can emerge during an unstable task where inaccurate force production leads to failure. Therefore, we aimed to investigate performance-stabilizing synergies in joint and highly unstable dynamic task. We hypothesized that performance-stabilizing synergies will be larger in one-person condition when compared to two-person, because subjects will heavily depend on haptic information during the unstable task. Twelve participants were asked to use their index and middle fingers of both hands to press on four force sensors distributed across a narrow board. The board was balanced on a rotating cylinder and subjects were told to keep the board horizontally, while cyclically moving it between two targets. The same task was also performed in two-person condition, with two subjects sitting side by side without any verbal communication. Uncontrolled manifold (UCM) analysis was performed to estimate performance-stabilizing synergies at the level of normal forces and moments of force. Overall, the task was successfully performed in both one-person and two-person conditions with forces and moments of force balanced. Normal forces and moments were consistently lower across the whole movement cycle when subjects performed the task together. Interestingly, performance-stabilizing synergies were higher for tasks performed together, therefore our hypothesis was rejected. Lower normal forces and moments may reflect presence of strategy to decrease high movement variability in order to successfully perform an unstable task in two-person condition. Additionally, increased performance-stabilizing synergies in two-person condition may suggested that the observed increased force and moment variability did not lead to the performance error because it was successfully compensated between two people.

Interactive effect of somatosensory and visual feedback on force production and coordination during isometric pressing tasks.

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Somatosensory feedback is essential to assist proper motor execution to accomplish dexterous manual movements. Previous studies have revealed different aspects of motor deficits in the absence of digital sensory feedback via local anesthesia during pressing and prehensile tasks. However, very few studies investigated the underlying motor coordination either between the deafferented and non-affected digits, or interaction with other sensory modalities such as vision. The current study evaluated both multi-digit motor performance and motor coordination during isometric pressing tasks, before and after selective digital anesthesia on a subset of fingers, with and without visual feedback.

14 healthy adults participated the study during two visits: Control (digital sensation fully intact) and Anesthesia (digital anesthesia applied on the right index and middle fingers). Subjects were asked to exert force by different finger-combination (2D: IM; 3D: IMR; 4D: IMRL) to match the task-required target force (20% of subject's maximal force) during a 20-s window. Visual feedback of target and produced force were displayed for subjects during the first 8 seconds ONLY. Two tasks were performed: Static and Dynamic, which required subjects either produce a target-matching force throughout the 20-s period, or produce two short target-matching force pulses (4s each) including initial one with visual feedback and the 'copy-action' one with no-visual feedback, respectively.

Our results showed that subjects' performance precision was reduced after accurate visual information was removed. This is particularly true after digital anesthesia for the Dynamic task but less so for the static task (when subjects simply continued to press). Additionally, removal of visual feedback elicited a significant force decrease during Static task in a drifting fashion, but less significant for Dynamic task which has much shorter force holding phase. Interestingly, subjects showed less force fluctuations within individual trials after digital anesthesia associated with reduced within-trial variability. A motor synergy index of across-trial-variability presented a significant drop due to visual feedback removal but not somatosensory feedback. These findings indicate that motor performance error induced by lacking information from one sensory modality can be compensated by additional information from another, with visual overriding somatosensory. This constellation of findings proposes a feedback control mechanism in the organization of the motor coordinative structure among the digits.

Exploring the concept of iso-perceptual manifold (IPM): A study of finger force matching task.

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We explored predictions of a scheme that views position and force perception as a result of measuring proprioceptive signals within a reference frame set by ongoing efferent process. According to this scheme, a stable percept can be formally represented as a manifold (IPM; Latash 2018) in the combined space of afferent and efferent variables. The main hypothesis tested in the study was: Accuracy of perception of an effector output is higher in one-effector tasks compared to multi-effector tasks.

We used two hands experimental set up, where with one hand (*task* hand) subjects were asked to move a cursor to a visual target which was set at 20% of the task hand's MVC. The *task* hand always had visual feedback of its performance. The *match* hand were instructed to reproduce the force that the *task* hand (F4) or individual fingers (F1) of the task hand were producing with brief matching episodes (3–4 s). Inter-trial variance was quantified within the uncontrolled manifold (UCM; Scholz and Schöner 1999) and orthogonal space (ORT) computed for total force.

Accuracy of individual finger force matching was worse in the four-finger task compared to the one-finger tasks. Also, both variance components, V_{UCM} and V_{ORT} increased during force matching by individual fingers in the four-finger task.

The difference in accuracy between the F4 and F1 conditions could be related to the subjects matching magnitudes of force modes (Danion et al. 2003) between the two hands leading to smaller forces in F4 related to the force deficit phenomenon (Li et al. 1998).

Sensory-motor impairment and hand usage choices following unilateral peripheral nerve injury.

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Few studies have investigated the behavioral consequences of unilateral upper extremity impairment, especially in the context of hand dominance. Here, we developed a pilot observational study to characterize the relationship between laboratory measurements of hand and arm capacity, hand usage (left/right choices in an unconstrained task), and quality-of-life factors (including activity participation and health-related quality of life) in unilateral peripheral nerve injury patients. We quantified capacity via ten measures of upper extremity function. Our primary measure of hand usage was a block-building task that forced participants to grasp and manipulate Lego bricks arranged across the workspace. We hypothesized that four measures of hand capacity (related to precision grip and sensory function) would predict atypical hand usage in patients with affected dominant hand, which would in turn predict changes in quality-of-life factors.

Our pilot data are consistent with some of our hypotheses. Based on data thus far (N=11), impairment to two components of hand capacity (both related to precision grip: Jebsen Hand Function Test "simulated feeding" and "small object pickup" subtests) is correlated with reduced usage of the affected hand ($r2 > 0.55$, $p < 0.01$). Moreover, patients with an affected non-dominant hand are more likely to use their unaffected hand ($p = 0.04$): in other words, patients with an affected dominant hand continue to use that hand despite its impairment. These pilot data suggest that there may be specific laboratory measurements that researchers can use as a proxy for broader behavioral consequences of unilateral impairment. No measures of hand capacity or usage appear to influence quality-of-life factors. A two-year, 192-patient full study is proposed to gain adequate statistical power.

Rehabilitation of hemispatial neglect with field-of-regard-focused visual exploration therapy.

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Although many patients experience significant recovery in the early phase after injury, the symptoms of hemispatial neglect (HSN) can persist for many years, and researchers have suggested that there is insufficient evidence to support the efficacy of available rehabilitation strategies. We examined the efficacy of field-of-regard-focused visual exploration therapy (FORVT) implemented using a head-mounted display (HMD) virtual reality system for HSN rehabilitation following stroke. Eligible participants were randomly assigned to one of two groups (training first (TF) or waiting first (WF)). The TF group completed 20 sessions of a FORVT program using an HMD (five daily sessions per week over a period of four weeks) followed by four weeks of waiting, while the WF group completed the opposite regimen. Nine of eleven participants exhibited deviations of the reference frame towards the ipsilesional side, while two participants exhibited no shifts in the reference frame. Recovery following the intervention ranged from 6–65%. Our results suggest that patients experienced improvements in motor-intention towards the left, as well as improvements in exploration equilibrium following FOVRT. The observed improvements in results on classic paper-and-pencil assessments represent both the translatability of these improvements to real-world function as well as the multi-dimensional effects of FORVT training.

"Nudged by vision: sensory cross-over in rapid feedback pathways that guide motor learning".

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Vision and proprioception provide congruent sensory information to guide our movements, and thus may play crucial role when a person re-learns to make desired movements after neural injury. As such, recent findings in healthy individuals suggest that the visual and proprioceptive pathways that generate rapid sensory-evoked motor responses are also integral to learning. However, these studies examined vision and proprioception in isolation, in stark contrast to natural motor behaviors where both sensory systems continuously work together to control movement. Understanding the coordinated contributions of vision and proprioception is necessary for determining if their interactions can be exploited to drive beneficial plasticity through a manipulation of either sensation using a cost-effective tool such as virtual reality. To this end, we tested whether adaptation in rapid visual pathway can also drive adaption in proprioceptive pathway. We adopted an experimental paradigm with two types of visual feedback previously demonstrated to enhance or inhibit the rapid, involuntary response to visual input. On two separate days, subjects ($n=14$) first reached in normal environment where they received veridical visual feedback of their hand, then reached in an environment with either enhancing or inhibiting visual distortions. To examine how both pathways adapt to these visual distortions, we randomly interleaved mechanical or visual perturbations to elicit rapid motor responses. Proprioceptive and visual responses were quantified using force measured at the hand, averaged over time windows corresponding to the earliest expected latency from each pathway: 110-160 ms and 160-240 ms from perturbation onset, respectively. We found that training visual adaption contributed to adaptation in the proprioceptive system. The rapid visual pathway adapted differently to the two distortions ($p<0.001$) as expected from previous work. This visual training led to similar adaptations in the proprioceptive pathways responding to mechanical perturbations ($p=0.03$). Across subjects, the amount of visual adaptation was correlated with the amount of proprioceptive adaptation ($r=0.73$, $p<0.01$), suggesting that the two observations are linked. Our result provides the first evidence of how visual inputs can be used to induce changes in rapid motor responses to proprioceptive stimuli. Understanding the interplay between the two sensory systems may contribute to our understanding of neurophysiological mechanisms that can be targeted to guide motor rehabilitation. However, the robustness of this effect, and its contribution to more general movements remains to be studied.

Proprioceptive evaluation of children with dyslexia.

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Developmental Dyslexia (DD) is a common learning disorder presenting specific impairments in reading (American Psychiatric Association 2013). Although several theories exist (phonological, cerebellar, attentional, magnocellular or sensorial) its etiology is unknown. Proprioception, the ability to know where our limbs are in space without vision (Proske, 2009), has not only sensorial origins but cognitive as well (Roll, 2006). Some studies investigating balance control suggest that proprioception may be deteriorated in DD children (Quercia et al. 2011).

The aim of our ongoing study is to evaluate and compare proprioception in children aged 9 to 12 years with and without dyslexia (with n=10; without n=12 up to now). We use an isokinetic dynamometer (Biodex Medical Systems) to passively move the arm and test proprioceptive acuity ontwo well-known tasks: a speed threshold detection task and a position matching task (Proske & Gandevia 2012).

Children are blindfolded for both tasks. In the speed threshold detection task, children are asked to report the passive motion of their arm by pressing a trigger (held in the opposite hand) as soon as they feel the motion. Twelve trials are performed for each of 6 different test velocities (0.25°s-1to 20°s-1; presented in a pseudo-random order). We record the time-delay necessary to detect the motion. In the position matching task, the elbow is passively flexed to a test position held for a few seconds and then returned to the start position. Then, a second passive flexion is performed by the robot and children are asked to press the trigger when their arm reaches the test position. Twelve trials are performed for each of three test angles (30°, 60° & 90°). We record the perceived position and compute the signed error with respect to the test position. In this experiment we control for the reaction time differences between groups (visual & auditory) and for the thixotropy effect on proprioceptive acuity (Proske & Gandevia 2012).

We observe similar reaction-time performance for DD and TD (typically developing), $p = .77$ for visual and $p = .82$ for auditory. The DD group, however, exhibits significantly longer time-delay than the TD group to detect the slowest movements ($p = .04$ at 0.25°s-1). DD children are also more variable than TD at this velocity ($p = .02$). A similar trend (not reaching statistical significance yet) is observed on the position matching task where DD children make greater errors than TD children.

Our study reveals proprioceptive deficits in children with dyslexia. We are currently including additional participants and plan to test for a possible link between the severity of the proprioceptive deficit and the reading deficit.

Knee proprioception impairments and its effect on balance post total knee arthroplasty.

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INTRODUCTION: While Total Knee Arthroplasty (TKA) surgery eliminates pain, and restores functional performance1, the procedure replaces biological tissues with a prosthetic knee joint, which may contribute to a reduced joint sense and proprioception. Previous studies have shown contradictory results regarding the relationship between TKA and loss of proprioception3,4. In addition, balance has been used as a surrogate to measure proprioceptive ability post-TKA5 making a broad generalization of current research difficult. Due to the contradictory findings in literature, the main objective of this study is to assess knee proprioception post-TKA. The second objective aims to determine the correlation between single joint proprioception measurement and balance assessment.

METHODS: 8 post-TKA (>3 months post-surgery) and 8 healthy age matched community dwelling participants participated in the study. To assess knee proprioception, participants performed the threshold to detect passive motion (TDPM) using the Biodex. Paired t-test was used to measure knee angle differences between limbs for each group. Independent t-test was used to measure differences between TDPM between groups. To assess balance, participants performed the sensory organization test (SOT)7 using the NeuroCom (Natus Medical Incorporated, San Carlos, CA). Composite scores (CS) were calculated during the SOT. In addition, Sample Entropy (SampEn) was used as a measurement for balance repeatability and predictability for the AP and ML center of pressure (COP) 8. Pearson correlation coefficients were calculated to assess the relationship between TDPM and SOT.

RESULTS AND DISCUSSION: T-test showed significant differences between limbs in both flexion ($p=0.02$) and extension ($p=0.04$) in the TKA group. Conversely, Healthy controls did not show proprioception deficits during either extension or flexion trials. Independent t-test showed significant differences between TKA and control groups TDPM deficiency during flexion trials ($p=0.01$) but failed to show significant differences during extension trials ($p=0.25$). CS showed no balance deficits in both groups. Flexion TDPM and SampEn AP COP showed significant negative correlations in the TKA group (r2; C4=0.47, C5=0.53, C6=0.45, $p<0.05$), while no correlations were recorded in the control groups.

Thus far, our results indicate deterioration in knee proprioception post-TKA. Although SOT measures the role of proprioception on balance, it should not be used as a proprioceptive measurement due to it assessing additional somatosensory systems (visual, vestibular) in a multi-joint scale rather than focusing on one particular joint. SampEn of the AP COP however may be an indicative of poor proprioceptive abilities post-TKA.

The role of posterior parietal cortex in hand choice: A fMRI-guided TMS investigation.

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Activities of daily living are characterized by the use of our hands, and deciding which hand to use to performs actions is a fundamental part of healthy, adaptive motor behaviour. According to traditional views, the brain systems responsible for the sensory guidance of actions are separate from those that mediate action choices. Accumulating data from multiple domains challenge this view, however, and suggest that those brain areas important for the control of actions also contribute to action selection.

Motivated by this evidence, we propose a new theoretical model of human hand choice: The Posterior Parietal Interhemispheric Competition (PPIC) model. The model suggests that populations of cells in bilateral posterior intraparietal and superior parietal cortex (pIP-SPC) encode actions in hand-specific terms, and compete for selection across hemispheres. Both hands are encoded bilaterally, but the contralateral hand is overrepresented.

Here, we use a novel fMRI-guided TMS paradigm to test the PPIC model. First, fMRI is used to identify brain areas involved in hand selection. Participants use either hand to reach to targets while in the scanner, and conditions involving free hand-choice are compared with when hand-use is instructed. Consistent with the PPIC model our results reveal the preferential involvement of bilateral pIP-SPC in hand choice, and for actions made with the contralateral hand.

Second, we target these same brain areas using continuous theta-burst stimulation (cTBS), a high-frequency repetitive TMS protocol shown to reduce cortical excitability, and measure subsequent hand choice behaviour using highly-sensitive psychophysical methods. The PPIC model predicts that cTBS to unilateral pIP-SPC will decrease the likelihood of selecting the contralateral hand. Data collection for this study is currently underway.

Altogether, our fMRI results reveal the involvement of bilateral pIP-SPC in hand selection, and our TMS study is expected to provide critical insights as to whether this involvement is necessary. Ultimately, our purpose is to establish the foundational science necessary to develop new adjuvant brain stimulation applications for upper limb rehabilitation. By targeting brain processes that govern hand choice, we hope to increase the likelihood that stroke patients will choose to use their affected hand, and with increased use, better functional recovery is predicted.

Increased gray matter density in the contralesional hemisphere of individuals with chronic hemiparetic stroke.

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Previous studies using functional neuroimaging techniques, such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI), have frequently reported increased motor-related neural activity in motor areas of both ipsilesional and contralesional hemispheres in stroke patients compared to healthy subjects. It is also reported that the more severe the impairment, the greater the activity in the contralesional hemisphere compared to the ipsilesional (i.e. a shift of activity to non-lesioned hemisphere). This alternative brain activity in individuals with chronic stroke over an extended period of time, may lead to brain structural changes. However, brain gray matter density changes in these individuals is not clear yet. The goal of this study therefore was to use Voxel-Based Morphometry (VBM) analysis on anatomical magnetic resonance images to identify the brain gray matter density changes over both hemispheres. 20 individuals with chronic (>1yr) hemiparetic subcortical stroke and 24 age-matched controls were recruited to participate in this study. Their MRI scans were collected on a 3T Siemens Trio magnetic resonance scanner at the Northwestern University Center for Translational Imaging. High resolution T1-weighted anatomical scans were obtained using a multi-shot gradient echo (GE) sequence with TR = 0.8 s, TE = 2 ms, matrix size = 256 x 256 x 176, and voxel size = 0.8 x 0.8 x 0.8 mm. SPM12 was used to segment structural images to gray matter, white matter and CSF tissues. Segmented images were modulated and normalized to MNI space while preserved for the total amount of tissue. Normalized gray matter images were smoothed with 6 mm FWHM Gaussian kernel and then used in a between-group two sample t-tests to compare the voxel-wise gray matter density changes in stroke patients compared to control group. Using voxel-wise corrected p value < 0.001 and p cluster-level corrected < 0.05, the brain and brainstem regions with increase/decrease gray matter density were identified. The stroke patients compared to healthy controls showed significant gray matter density increase over contralesional hemisphere especially in premotor, motor and sensorimotor cortices. As the result of proximity and connectivity with lesioned region, ipsilesional thalamus and putamen showed significant decrease in gray matter density.

Magnetization transfer imaging of the cervical spinal cord suggest subtle demyelination may underlie sensorimotor impairments after whiplash injuries.

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Objective: Magnetization transfer imaging was used to provide a quantitative measure towards identifying physiologic changes in cervical spinal cord anatomy in a small sample of subjects with varying levels of recovery following whiplash injury due to a motor vehicle collision (MVC).

Summary of Background Data: Half of all people with neck pain following a MVC should expect to fully recover within 2-3 months while the remaining 50% will not; some of which (~25%) continue to have moderate to severe sensorimotor impairments such as weakness, fatigue, and pain. While the mechanics of a typical rear-end vector impact suggests a potential insult to a number of anatomical tissues, evidence of structural pathology with available clinical imaging techniques remains elusive.

Methods: Magnetization transfer ratios (MTRs) were measured in the cervical spinal cord of 15 participants: 5 with moderate to severe symptoms (from 3-months to 3-years), 5 that self-nominated full recovery at 3 months, and 5 healthy controls. The homogeneity in MTR response (MTRh) was calculated using region-of-interest analysis across the ventromedial, dorsolateral (left and right) and the dorsal aspects of ascending and descending white matter tracts. The lateral corticospinal, dorsal columns, and spinothalamic white matter tracts were analyzed using the open source Spinal Cord Toolbox.

Results: The participants with chronic whiplash had significantly different MTRh compared to healthy controls and recovered participants ($p = 0.02$). In addition, MTRh was correlated with self-reported disability ($p < 0.001$) with the moderate/severe group having the largest MTRh values (Chronic whiplash 0.23, Recovered: 0.13, Control: 0.10). Comparison of MTR values of specific tracts demonstrated marked decreases in all participants with poor recovery.

Conclusions: A high resolution (0.5mm in-plane) quantitative imaging technique of the cervical spinal cord was utilized and implies focal changes suggestive of demyelination in specific white matter regions with greater inhomogeneity of the magnetization transfer ratios in the group with poor recovery. Recovered and healthy controls do not have such findings. Specific white matter tract analysis further suggests focal changes in myelination, which correlate with patient-reported outcomes.

The prognostic utility of EEG: a systematic review.

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Introduction. Post-stroke recovery might be optimized through the implementation of individualized treatment. Evidence suggests that EEG has critical implications for prognosis and demonstrates the capacity to predict clinical outcomes in the stroke population. Thus, EEG might serve a fundamental role in the management of stroke recovery and allocation of treatment to likely responders. However, no systematic reviews have analyzed the prognostic utility of EEG in stroke recovery.

Aims. To review recent literature on EEG; to provide an overview of EEG as a prognostic tool; to provide clinicians with an overview of an evidence-based approach that might effectively direct and prioritize treatment.

Methods. A literature search was conducted using three electronic databases: PubMed, Scopus, and CINAHL. A similar strategy was used to identify concepts related to "EEG" and "rehabilitation" in all three databases. Only peer-reviewed journal articles were included in the review.

Results. Thirteen papers met the inclusion criteria. In all studies, EEG was utilized to make statistically significant predictions in regard to clinical outcomes. Discrepancies were present among the studies, including the EEG protocol implemented and biomarkers chosen for analysis, making direct comparisons difficult.

Conclusion. EEG has demonstrated prognostic value in regard to stroke recovery. Brain activity recorded using EEG following stroke has been correlated with short and long-term clinical outcomes and is generally superior to corresponding clinical assessments. However, further research analyzing the most effective, yet feasible, protocol is needed.

Cholinergic modulation of reinforcement learning in the striatum.

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Variability in corticospinal excitability during motor planning contributes to grasp force variability in humans.

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Trial-to-trial variability in grasp forces during manual tasks is a ubiquitous feature of motor control. Such an across trial variability in grasp forces has been known to arise primarily from the neuromuscular noise during movement execution. However, neural processes during motor planning may also contribute to across trial variability. Monkey work showed that the variability in the firing rate of neurons within primary motor cortex (M1) during motor planning contributed to across trial variability in reach endpoint. However, in humans, whether neural mechanisms during motor planning contribute to across trial variability in grasp forces remain to be known. In this study, we sought to determine whether a measure of variability at the neuronal population level such as variability in corticospinal excitability (CSE) during motor planning contributes to across trial variability in grip forces applied to an object. We used fluctuations in peak to peak amplitude of motor evoked potentials (MEP) elicited using transcranial magnetic stimulation (TMS) to quantify CSE variability. Twelve healthy young subjects participated in two separate sessions at least 2 days apart. First, we assessed the intrinsic variability in MEP as a function of MEP amplitude at rest. In another session, subjects were visually-cued to grip an object at a fixed location using the index finger and thumb by exerting either a low grip force (LF; 5% of maximum pinch force or MPF) or high grip force (HF; equal to 30% of MPF). TMS was delivered at one of the six latencies from the ‘task’ cue in a random order: 0.5, 0.75, 1 (‘go’ cue), 1.1, 1.2, and 1.3 s. We obtained a model that predicts MEP variability based on its amplitude using MEP data at rest. We, then, estimated the task relevant CSE variability as a difference between the variability observed during the force task and the variability predicted by the model. We found that the task relevant MEP variability varied during force planning. Specifically, we observed a significant increase in the task relevant MEP variability from 1.2 to 1.3 s following the task cue but prior to movement onset. This modulation was observed only for the HF task, but not for the LF task. The modulation in the CSE variability during the latter phase of force planning may represent the convergence of task-related inputs onto M1. Importantly, we observed that larger task relevant MEP variability was associated with larger across trial force variability for the HF task. Our findings, for the first time, provide evidence for the contribution of the force planning stage to trial-to-trial variability in grasp forces in humans.

Interaction between feedforward and feedback postural responses induced by respective perturbations.

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The purpose of this study was to investigate the interaction of muscle activities during feedforward and feedback postural responses. Eight healthy men participated in this study. A novel experimental method was developed to manipulate the magnitude of perturbations to elicit anticipatory postural adjustments (APA) and compensatory postural responses (CPR). Eight tasks combining three body-mass loads were used to elicit APA and three other body-mass loads were used to elicit CPR. In this study, CPR amplitudes were unchanged when the magnitude of disturbance used to elicit CPR was the same, despite last-minute APA amplitude changes within the same trial. On the other hand, APA amplitudes changed in accordance with different CPR amplitudes when the magnitude of perturbation to elicit APA was the same. This suggests that APA and CPR are controlled independently. In addition, APA amplitudes would be modulated by the previous postural disturbance magnitudes, not just the magnitude of the internal perturbation associated with voluntary movement. These findings suggest that separate training approaches are required to enhance APA amplitude and CPR amplitude in the field of rehabilitation.

Two forms of sway-referenced haptic feedback improve standing center of mass stability in a person with post-concussion syndrome.

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Introduction: Post-concussive individuals often suffer from chronic vestibulo-ocular deficiencies and subsequently develop postural control instability while standing. To reduce fall risk, a maladaptive dependency on vision or tactile input can develop. Point-of-contact reaction forces from the light touch of a finger or another person have been shown to improve stability by providing sway feedback relative to a earth-fixed reference. Unfortunately, these aides require use of the hands and, thus, limit functional activity. The purpose of this study was to develop a wearable form of haptic input that provides a hands-free ground-reference for reducing center of mass (COM) sway in a visually-dependent post-concussive patient. Methods: A collegiate softball player with significant concussion history suffered balance deficits in community environments, requiring hand-based stabilization in low-light conditions and a continuous view of the feet or ground to avoid falls. Two novel wearable devices were designed and constructed to provide a haptic reference to ground. Both devices used an array of 6 actuators positioned on the upper thorax, driven by a sway detection algorithm relative to trunk orientation. One device used custom-built actuators that generated light touch perpendicular to the skin ('touch device', approximately 5N); the other device used vibration actuators ('vibration device'). COM behavior was assessed during 15-second trials of static standing using a 3D motion analysis system (10-camera, 2 force plates). Five "standing support" conditions (i.e. using a cane, wearing the haptic vibration device, etc) were crossed with five "standing challenge" conditions (i.e. on foam; with visual conflict, etc.) Results: Measures of COM stability were significantly improved while wearing either haptic device, outperforming other forms of support. Across all conditions, haptics reduced AP sway excursion 36% on average, and up to 52% on foam. Discussion: This examination of one patient under multiple conditions suggests that sway-referenced haptic feedback can be effectively employed to provide a hands-free ground reference that reduces COM instability in standing.

Slackline: a method to train postural balance, core endurance and cognitive functions.

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Introduction: Static and dynamic balance performance is an important skill to develop during the cycle of life and especially in sporting life. Slackline-training has been shown to improve mainly task-specific balancing skills, but also some cognitive functions. Here we test whether Slackline practice induce changes in postural balance, in Core endurance and in two cognitive functions: attention and visual memory. Methods: 12 Slackline athletes (24,1 ±4,2 years old) and 12 control volunteers (22,4 ± 1,8 years old) were evaluate by Y balance test to assed dynamic postural Balance in two conditions: stable and instable, and also the center of pression (CoP) were measured -only to the Slackline group- in Bipodal, both unipodal left and right as stable condition and also the unstable sitting test was applied. To asses core endurance Mc Gill test, plus bilateral plank test were applied. Attention were measure applying the Toulouse-pieron test, while memory were measured applying the visual Benton Visual Retention Test. Results: The results are intergroup comparisons, except for the CoP. In all cases, only those with significant differences are presented ($p<0.05$). Regarding the dynamic Balance, only differences in the unstable condition were observed between groups around 25 % more distance reached by the Slackline group with the left foot supported in the anterior displacement and in the postero-medial displacement as well as the anterior displacement with the right food. The CoP results were analyzed by the root mean square (RMS) were the higher values are observed in the unipodal condition (without differences between left or right feet; M-L 0,133 vs 0,123 respectively and A-P: 0,182 vs 0,181). The RMS in Bipodal condition were M-L: 0,042 ± 0.015 and A-P: 0.093 ±0.025 and the unstable sitting condition M-L: 0,068 ± 0,046, A-P: 0,073 ± 0,031. Related to Core Endurance, differences were observed in the bilateral plank test between the Slackline group (78,59 ± 40,65 s) and the control group (42,80 ± 16,66 s) and in the left trunk lateral test, were Slackline group were able to maintain it by 70,30 ± 31,64 versus 21 ± 17 s maintained by the control group. Regarding the attention and memory test, Slackline group score 12 % and 20 % over the control group respectively. Conclusion: the systematic practice of at least of 2 years of Slackline could contribute to improve dynamic balance and core endurance, and moreover it could improve attention and visual memory, therefore Slackline could constitute a tool to improve sport performance as well as a tool for rehabilitation.

The Romberg test in cancer survivors with neuropathy.

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BACKGROUND: Over 15.5 million cancer survivors are currently living in the United States. Neuropathy is a common side effect from cancer treatment, affecting up to 50% of cancer survivors. The impact of neuropathy on postural control in cancer survivors is poorly understood. The purpose of this study was to determine differences in postural stability between cancer survivors with and without neuropathy, and age-gender matched controls. METHODS: Seventeen cancer survivors and twelve healthy controls were recruited from the community. Cancer survivors were included if they had any cancer diagnosis and completed chemotherapy treatment. Participants were divided into three groups: cancer survivors without neuropathy (n=9), cancer survivors with neuropathy (n=8), and healthy controls (n=12). All participants performed two 30 s trials of static balance tests with their eyes open (EO) and eyes closed (EC) while standing on a force plate. A monofilament test was performed on nine sites at bottoms of both feet to measure cutaneous sensation. Self-reported neuropathy symptoms over the last seven days were reported. Center of pressure (COP) was extracted from the force plate, and COP Velocity radial was extracted. The Romberg Ratio, the ratio between eyes closed and eyes open, was calculated and averaged. The Romberg ratio provides insight to the vestibular and proprioceptive contribution to postural control. A one-way ANOVA with Tukey's post hoc analysis was conducted. RESULTS: Average age of all participants was 55.7 years, and four were males. Of those with cancer, ten were breast cancer survivors. Average COP Velocity EO was 0.76 cm/s for controls, 0.80 cm/s for cancer survivors without neuropathy, and 1.04 cm/s for cancer survivors with neuropathy. Average COP Velocity EC was 0.98 cm/s for controls, 1.17 cm/s for cancer survivors without neuropathy, and 1.69 cm/s for cancer survivors with neuropathy. There was not a significant main effect for COP velocity EO ($p = 0.191$) or COP velocity EC ($p = 0.095$). There was a significant main effect for Romberg Ratio for COP Velocity ($p = 0.035$). Post-hoc analysis indicated a significance difference in Romberg Ratio between the control group and neuropathy group ($p = 0.028$). There were no significant differences between the control group and cancer group ($p = 0.609$; Cohen's $d = 0.470$) or between the cancer group and neuropathy group ($p = 0.218$; Cohen's $d = 0.949$) for Romberg Ratio. DISCUSSION: Cancer survivors with neuropathy demonstrate greater postural impairment compared with cancer survivors without neuropathy and controls. Future work should determine the impact of types of chemotherapy on gait and postural control in cancer survivors, and whether interventions targeting neuropathy may improve postural control.

Postural control and spatial orientation in patients with unilateral peripheral vestibular lesion.

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Introduction: For an optimal motor control it is necessary that brain integrates properly vestibular, visual and somatosensorial inputs. When unilateral peripheral vestibular lesion occurs, elaboration, interpretation and processing of inputs are deficient and therefore postural control and movement are altered. As the process progresses in time, spontaneous neuroplasticity in the brain facilitates recovery or compensation of the vestibular function. Nevertheless this spontaneous mechanism is sometimes incomplete and symptoms could persist for years. The main symptoms are visual vertigo and postural unbalance. Objectives: To evaluate the efficacy of a postural rehabilitation program (PRP) in a group of patients with symptomatic unilateral peripheral vestibular dysfunction (UVL).

Methods: Quality of static and dynamic balance was registered with a force plate (Synapsis®). Subjective-visual-vertical perception and visual-orientation perception were analysed with the bucket test. Reference values were obtained in an age-matched control group. Patients carried out 12 sessions of PRP. Assessment was carried out before and after treatment for UVL participants. Further analyses were performed to take into account the time course of UVL evolution and the side of the lesion.

Results: Balance control and spatial orientation improved in most UVL subjects after postural rehabilitation. In fact, PRP was most effective in the acute phase and in right vestibular lesions, as also shown by the DHI clinical scale. Patients with greater visual dependency or greater difficulties in integrating sensory inputs showed lesser improvement. The side of vestibular lesion played an essential role in the perception of verticality. Tests of visual orientation (VO) showed a disturbance of egocentric references in the acute period of UVL with recovery during the chronic phase.

Conclusions: PRP provides a reweighting of multisensory integration, increasing the confidence in proprioceptive afferences and decreasing dependency on visual afferences. The results of this weight modulation are associated with a reduction in symptoms associated with vestibular lesions.

The impact of constraint severity on the coordination of simultaneous postural and manual tasks.

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Dual-task activities such as maintaining posture while reaching for an object require the same set of joints to be controlled in order to satisfy constraints imposed by the disparate tasks. In this study, we examined changes in the structure of joint angle variance as the constraints on the postural and manual components of a standing precision fitting task were systematically altered. We hypothesized the joint variability will be structured to stabilize both the postural and manual tasks. We also explored changes in task-specific variance components using the uncontrolled manifold (UCM) analysis.

Ten subjects (22±2.7 yrs) fit a block (area 81cm2) through a small (121 cm2) or large (196 cm2) opening that was placed at 4/3rd arm length while standing on an 8 cm high platform with either a narrow (1/3rd foot length) or wide (35 cm) anterior-posterior length. Participants repeatedly transported and held the block in the opening for 5s.

We performed UCM analysis on 20 error-free trials (no block contact with the opening; no tilting of platform). The across-trial variance of 13 joint angles was partitioned into a task-irrelevant component along a UCM (Vu) and a task-relevant component along an orthogonal manifold (ORT; Vo) for the control of (1) the body's COM position and (2) hand position. The relative amount of Vu in the total variance was computed (DVz) and used to quantify task-specific covariation in the joint angles that separately stabilized each set of task variables (3D COM and hand position). Higher DVz indicates greater stability of the output variables. A two-way repeated measures ANOVA (platform width x opening size) was conducted on all UCM variables.

DVz values indicated that the joint angles co-varied to stabilize both COM and hand positions. However, platform width and opening size changes did not alter DVz values for either task-variable set ($p>0.05$). Vu for COM and hand position increased when opening size decreased, but only when standing on the wide platform ($p<0.05$). Surprisingly, hand position Vo was higher for the smaller opening size ($p<0.05$).

The UCMs and ORTs for the two tasks are not mutually orthogonal. Therefore, Vu with respect to the postural task creates Vo for the manual task. Therefore, while standing on a wide platform, higher hand position Vo for smaller opening size arises from insufficient postural stabilization. In contrast, the postural challenge imposed by the narrow platform may have induced high co-contraction, resulting in invariant Vu, but higher Vo for hand position for smaller opening size. Thus, postural task constraints dominated changes in joint-angle variance, suggesting that postural control is prioritized.

Standing balance control with voluntary co-activation.

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Introduction: Quiet standing requires complex coordination of muscles across multiple joints to prevent the many collapse modes of the multi-segmented body. Sagittal-plane coordination can be quantified from the temporal patterns observed in the force of the ground on the feet (F). Previous work reported tight covariation of the F center-of-pressure (CP) and direction (θ) [Zatsiorsky & Duarte 1999] within narrow frequency (f) bands [Boehm, Nichols, & Gruben 2018]. That covariation can be geometrically described as an intersection point (IP) of the F lines of action. The height of the intersection point (zIP) with respect to center of mass (zCM) was observed to vary with f reflecting neural coordination; zIP is close to zCM at about 1.75 Hz but differs from zCM at other frequencies. Here we explored effects of voluntary muscle co-contraction on patterns of postural sway and zIP(f) curve.

Methods: Ten unimpaired humans stood for one minute either with typical muscle activation or with graded voluntary lower-body co-activation. Postural sway was decomposed into trembling and rambling [Zatsiorsky & Duarte 1999, 2000].

Results: The zIP(f) curve shifted higher (or to greater frequencies) when participants co-activated muscles voluntarily. zIP correlated with the power of trembling across frequency bins ($R > 0.9$ in each subject).

Discussion: Various zIP are necessitated by the task objective of maintaining near upright posture. It may be expected that the nervous system would activate lower inertia modes (low zIP) with more rapid and short duration temporal waveforms and vice versa yielding the hyperbolic curve observed. The zIP(f) curve may result from a few control modes (e.g., referent body configuration templates) that lead to a few consistent muscle activation modes and corresponding joint torque modes. The upward shift of the curve with co-activation demonstrates that neural changes can alter this pattern. Additionally, co-activation is expected to increase the apparent stiffness of the joints and lead to faster trembling component of sway paired to faster rambling as the means of balancing the system. In summary, quantifying zIP(f) provides a convenient simple measure that relates directly to the mechanics of the task and to the coordination of muscles across the whole body.

Relating smooth arm cycling to the control of interaction torque.

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We demonstrated the decomposition of Cartesian endpoint jerk to components related to angular velocities, accelerations and jerks in the shoulder and elbow, in human reaching. Three main components were identified that are functions of both the kinematic variables in the joint space and time derivatives of the Jacobian transformation between joint and Cartesian space. In a point to point reaching movement the main component influencing the behavior of the endpoint jerk was found to be directly correlated to the angular jerk. When analyzing more complex movement we found that the angular jerk component is not sufficient to fully represent the endpoint jerk. This was tested in a common rehabilitation exercise such as arm cycling.

The participant was seated in a fixed chair in front of an arm cycle ergometer (MEYRA, Kalletal, Germany), grasped the handle of the ergometer at the end of the crank (which was 10 cm long) and performed arm cycling (drove the ergometer) with a cadence of 60 revolutions per minute. The distance between the chair and the ergometer was set in such a manner, that when the handle of the ergometer was at the most distant position with respect to the participant, the external angle of the elbow was approximately 10-15 degrees. This corresponded to the most extended elbow position. The shoulders were strapped to the back of the chair to restrict the movement of the trunk. Ultrasound emitting markers of an ultrasonic movement analyzer system (ZEBRIS CMS HS, Isny Germany) were placed on anatomical landmarks of the participant's arm. The positions of the markers were recorded with a sampling frequency of 100 Hz. Inter-segmental angles in the shoulder and elbow were computed from marker positions.

We considered the movement of the arm in the osculating plane passing for the center of rotation of the shoulder, the elbow and the knuckle of the 5th finger. This allowed us to compare the experimental values with a simulation in which we rendered a movement obtained at perfect constant velocity of the crank, and with simulated impairments where the interaction torques between shoulder and elbow was not compensated. We have observed that for the cycling movements, lack of compensation of interaction torque produces an equalization of jerk components and could be used as an index to characterize the severity of the impairment. This work was supported by the grant GINOP 2.3.2-15-2016-00022 and The Cooney-Jackman Endowed Professorship.

Locomotor stability effort changes maneuver execution in Incomplete Spinal Cord Injury.

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The recovery of locomotor stability – the ability to maintain a desired walking trajectory amid perturbations – and maneuverability – the ability to change walking trajectory – are major gait rehabilitation challenges for ambulatory individuals with incomplete spinal cord injury (iSCI). Although essential for community ambulation, it is difficult for people with impaired motor function to simultaneously optimize both stability and maneuverability, and, instead, preferred strategies often result in conflicts between the two. We hypothesized that following walking practice in a robotic force field that increases effort to maintain straight walking, individuals would adopt gait patterns that are more resistive to lateral maneuvers, and, conversely, following practice in a force field that decreases stabilization effort, individuals would adopt gait patterns less resistive to maneuvers. 12 individuals with iSCI and 12 non-impaired individuals provided consent and performed straight walking in three force field conditions: 1) Null: no external forces. 2) Damping: Force field proportional in magnitude and opposite in direction to lateral COM velocity 3) Amplification: Force field proportional in magnitude and in the same direction as lateral COM velocity Immediately following straight walking, the force field was removed, and participants made lateral walking maneuvers. We quantified the number of steps to complete the first maneuver and minimum step width and minimum lateral margin of stability during the maneuver. We found no significant differences between groups. Following the Amplification field, individuals took more steps to complete the maneuver and increased step width and lateral margin of stability during the maneuver compared to the Null field. Conversely, after walking in the Damping field, individuals decreased step width but did not alter lateral margin of stability during the maneuver. These changes did not result in significant differences in steps required to complete the maneuver. Our results suggest that the control strategies used to create stability have consequences for maneuvering. After the Amplification field, the strategies participants used to create lateral stability likely increased resistance to perturbations and to their own volitional efforts to change direction. Developing interventions that improve the ability to either rapidly switch between control strategies or to learn alternative strategies that better facilitate simultaneous control of both stability and maneuverability would expand the variety and complexity of environments for community ambulation.

Lower limb coordination following spinal cord injury and its relation to proprioceptive sense.

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Background: In individuals with motor-incomplete spinal cord injury (m-iSCI), functional ambulation is compromised, partly due to the complexities of skilled walking (e.g. obstacle avoidance, negotiating a curb, etc.) in our everyday lives. The ability to modify gait patterns for skilled walking requires appropriate inter-joint coordination. Following SCI, inter-joint coordination can be impaired not only due to motor impairments, but also proprioceptive deficits. In this project, we developed a new protocol for testing inter-joint coordination in the legs with the aim of understanding the impact of proprioceptive deficits in people with SCI on lower limb coordination.

Methods: Individuals with m-iSCI and able-bodied individuals were recruited. Clinical measures of skilled walking function and lower limb proprioceptive sense were characterized in the subjects with SCI. All subjects then completed a lower limb pointing task where they aimed their toe from a "home position" to one of three possible targets. Each target required varying degrees of inter-joint coordination and the excursion of the leg to each target was normalized to every individual's active range of motion. The pointing task was completed under full and obstructed vision conditions. Motion capture markers were used to determine foot trajectory, as well as hip, knee and ankle angles. From the kinematic data, end-point (toe) accuracy and inter-joint coordination, quantified by joint angle-angle plots, were extracted.

Results and Conclusions: Individuals with SCI had impairments in lower limb proprioceptive sense. When pointing to the different targets, individuals with SCI showed poor control of end-point accuracy and disordered lower limb coordination that was especially exacerbated in the obstructed vision condition. Lower limb coordination was related to lower limb proprioceptive sense, such that poor coordination was related to greater proprioceptive deficits. On the other hand, able-bodied individuals accurately pointed towards all targets and displayed appropriate lower limb coordination in both the full and obstructed vision conditions. The results show that this protocol is a suitable tool for measuring lower limb coordination and provides a new approach for future studies to examine how lower limb coordination affects functional ambulation.

Effect of coil orientation on motor evoked potentials in humans with tetraplegia.

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The corticospinal tract undergoes reorganization following spinal cord injury (SCI). However, the extent to which we can activate corticospinal neurons by using noninvasive stimulation after the injury remains poorly understood. To address this question, we used transcranial magnetic stimulation (TMS) over the hand representation of the motor cortex to elicit motor evoked potentials (MEPs) using posterior-anterior (PA) and anterior-posterior (AP) induced currents in the brain and compared them with responses evoked by direct activation of corticospinal axons using latero-medial (LM) currents. Testing was completed during small levels of index finger abduction in humans with and without (controls) cervical incomplete SCI. We found prolonged MEP latencies in individuals with SCI in all coil orientations compared with controls. However, latencies of MEPs elicited by PA and AP stimulation relative to those elicited by LM stimulation were shorter in SCI compared with control subjects. Notably, the largest difference between SCI and control subjects was present in MEPs elicited by AP currents. Using a novel controllable pulse parameter TMS, we also found that MEPs elicited by AP currents with 30 μs compared with 60 and 120 μs pulse width had increased latency in controls but not in SCI subjects. Our findings demonstrate that differences between corticospinal responses elicited by AP and PA induced currents were not preserved in humans with tetraplegia and suggest that neural structures activated by AP currents changed largely after the injury.

Is Stability Compromised during Walking Maneuvers in Individuals with iSCI?

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Previous research on non-impaired populations has found that in anticipation of a maneuver, people reduced their lateral margin of stability (MOS) ipsilateral to the maneuver [1]. Decreases in MOS may improve ability to maneuver by reducing the body's resistance to volitional impulses [2], however, decreases in MOS may also decrease resistance to external perturbations. If not managed, this potential stability-maneuverability trade-off may have large and dire consequences for ambulatory individuals with incomplete spinal cord injury (iSCI). This research aims to quantify changes in resistance to perturbations between walking environments with or without the demand for lateral maneuvers. We hypothesized that CM excursion following perturbation in the maneuver condition would be greater than in the straight walking condition. An individual with incomplete spinal cord injury (iSCI) and noticeable asymmetric weakness on his left side walked on a wide treadmill during two tasks. During all walking, we projected the participant's lateral center of mass (CM) position on the treadmill belt. We instructed the participant to try to maintain his CM projection within a 20cm wide target lane. In the straight task the target lane was static. In the maneuver task, the target lane unexpectedly switched between the right and left sides of the walking surface every 3-6 steps. During each task, 8 medial perturbations (40N, 200ms) were randomly delivered to the CM level at heel strike. Perturbations during the maneuver task occurred during "straight" walking prior to the target lane switching positions. Perturbation direction during the maneuver task was directed in the same direction as the upcoming maneuver. Peak CM excursion following the perturbations did not support our hypothesis. CM excursions following leftward perturbations were on average 31% less than during the maneuver than the straight walking task. There were no observable differences in CM excursions for rightward perturbations. We did not observe differences in lateral MOS during non-perturbed steps between the straight and maneuver tasks. This preliminary data suggests that individuals with iSCI may select walking strategies that preferentially favor stability over maneuverability. The multifactorial nature of stability was highlighted by the larger CM excursion during the maneuver task compared to the straight walking task with leftward perturbation, even though MOS was similar. Further work should be conducted to more completely characterize this potential increased stability in anticipation of maneuvers and how strategies may differ between individuals with and without iSCI.

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Tonic transcutaneus lumbar cord electrical stimulation facilitates the exoskeleton walk training for paralyzed patients.

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We studied the effect of spinal cord electrical stimulation (SCES) on the exoskeleton walk training (EWT) in 18 SCI patients (Frankel Class A-10, B-4, C-4) during an intensive 2-week rehabilitative course. Ten patients had flaccid and 8 – spastic paraplegia with post-trauma period > 1.5yrs. All patients were experienced in treadmill walking, five of them previously received transcutaneous electrical stimulation of the lumbar cord to activate the locomotor neuronal networks. For EWT, we used a powered 'ExoAtlet' exoskeleton (Russia). EWT included 12-15 sessions of about 730 min of wearing and 320 min of walking in the exoskeleton per subject. In the initial sessions, patients practiced walking assisted by two therapists. After 3-4 sessions, they demonstrated relatively stable walking with one assistant for safety. Beginning from the 6-th session, tonic low-frequency SCES was applied to the mid-lumbar cord with the electrodes placed on the skin over the Th12 vertebra and the abdomen. The basic frequency of SCES was 1 Hz (n=6) or 3 Hz (n=12); two patients with severe muscle spastisity (Ashworth score 4) additionally got 30 Hz SCES. The duration of the stance, swing and double support phases, and the vertical component of the ground reaction forces (GRF) were analyzed using the F-Scan system. SCES significantly increased the magnitude and decreased the asymmetry of stepping and GRF both within a session and between the two sessions. After EWT, 6/18 patients showed an increase of tactile and pain sensitivity, more frequent within the group getting 1 Hz SCES. All patients noticed facilitation when walking with SCES, 15/18 reported paresthesia in leg muscles, new non-differential feeling of passive motion in leg joints and 'sense of support'. Leg muscle strength gain was obtained in 6/12 patient training with 3 Hz SCES, no cases of muscle strength increase was observed with 1 Hz SCES. Two patients with severe muscle spastisity with SCES were able to perform exoskeleton-assisted walk. The C-class patients significantly improved the locomotor performance by increasing the maximal walking distance, velocity and stride length.

The results suggest that SCES facilitates training and walking in the exoskeleton in SCI patients by activating the locomotor networks and augmenting compensative sensitivity. SCES in the special antispastic mode can also decrease spasticity.

A dual-learning paradigm simultaneously improves multiple features of gait post-stroke.

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Gait impairments after stroke arise from dysfunction of one or several features of the walking pattern. For example, after a stroke many patients experience a step length asymmetry, where one leg advances further than the other, in addition to stiff-knee gait, where the paretic leg has insufficient knee flexion. Traditional rehabilitation practice focuses on improving one component at a time, which may leave certain features unaddressed or prolong rehabilitation time. Recent work has shown that neurologically-intact adults can learn multiple movement components simultaneously. Here, we sought to determine whether a dual-learning paradigm, incorporating two distinct motor tasks, can simultaneously improve two impaired components of the gait pattern in people post-stroke.

Thirteen adults with chronic stroke participated in this study. All participants completed two sessions during which they were provided visual feedback of the amount of paretic knee flexion during walking. During the learning phase of the experiments, an unseen offset was applied to this feedback to promote increased paretic knee flexion. During the first session, the knee task was performed while walking on a split-belt treadmill intended to improve step length asymmetry. During the second session, it was performed during traditional tied-belt walking.

We found that the dual-learning task simultaneously increased paretic knee flexion and decreased step length asymmetry in the majority of people post-stroke. Importantly, there was no interference between the motor tasks in the dual-learning condition: the magnitude and rate of knee-flexion learning did not differ from that of the joint-angle learning task alone. Our results suggest that people with chronic stroke may benefit from a dual-learning paradigm for gait rehabilitation. Given the complex nature of gait impairments post-stroke, this type of combination-therapy approach may make rehabilitation more efficient by addressing multiple deficits simultaneously, rather than in succession.

Changes in muscle activation between one- and two-legged pedaling.

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In the 2016 Paralympic at Rio, Brazil, a cyclist pedaled with a single leg due to amputation of the other leg. One-legged pedaling has been suggested as a training tool for elite cyclists and patients with unilateral limb function deficit and chronic obstructive pulmonary disease. Therefore, it is important for coaches and clinicians to understand muscle activation patterns in one-legged pedaling.

Muscle activations in one- and two-legged pedaling have been compared, with one study reporting higher overall activation amplitudes for biceps femoris, vastus lateralis, rectus femoris, tibialis anterior, and medial gastrocnemius. However, another study showed less vastus lateralis activation from 30 to 130 degrees of the crank cycle when pedaling with independent crank arms. This study examined only 6 leg muscles, so the activation of other major leg muscles in one-legged pedaling is unclear. Thus, the aim of this study was to compare muscle activation amplitudes of eleven leg muscles between one- and two-legged pedaling throughout the crank cycle.

Ten healthy young participants cycled at 30 rpm with power outputs of ~ 60 Watts and ~ 30 Watts. Electromyography (EMG) data were collected from eleven muscles of the left leg: tibialis anterior (TA), soleus (SOL), medial gastrocnemius (MGA), lateral gastrocnemius (LGA), vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), biceps femoris long head (BFL), semitendinosus (ST), tensor fasciae latae (TFL), and gluteus maximus (GMAX). EMG data were rectified and filtered to produce EMG linear envelopes and normalized by the peak value of each muscle found in two-legged pedaling. Muscle activation amplitudes were quantified by integration under each quadrant of the EMG linear envelopes.

In one-legged pedaling, larger muscle activation amplitudes were found for TFL, ST, BFL, TA, and MGA muscles, which are hip, knee, and ankle flexors. These increases originate from the absence of torque support from the other leg during the upstroke phase. In the downstroke, muscle activation amplitudes decreased for the extensors VM, VL, RF, and SOL, resulting in reduced peak crank torque during the downstroke. Interestingly, GMAX activation amplitude increased in late upstroke, suggesting the muscle may act as a hip abductor to stabilize the hip joint. Future studies with measurement of 3D joint kinematics and kinetics are needed to fully explain the increased GMAX activation.

Changes in dimensionality of movement trajectories with different walking speeds.

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Walking is a complex motor skill that involves the coordination of many degrees-of-freedom. Degrees-of-freedom at the kinematic level can be quantified as the dimensionality (D) of a movement trajectory in phase space. Previous research has estimated that for movement trajectories of the human body during walking $D \approx 5$ or 6. Preferred movements are hypothesized to have lower dimensionality and therefore be simpler to control. While humans readily adopt a preferred walking speed and cadence, it is not known if this corresponds to minimal dimensionality of movement trajectories. Additionally, the dimensionality of movement trajectories of one body part is expected to be related to those of other areas. To test these two hypotheses, twelve participants walked overground along a 65 m walkway at five speeds relative to their individual preferred walking speed: 50, 75, 100, 125, and 150%. Sagittal plane motion for both knees was recorded with electrogoniometers. Acceleration in antero-posterior (AP), medio-lateral (ML) and vertical (VT) axes was measured at the trunk and head using triaxial accelerometers. Dimensionality of each movement trajectory was estimated via the correlation dimension. For both left and right knee trajectories $D \approx 3$ and was quadratically related to walking speed (R2 = .69 and .70, respectively). In agreement with the prediction, minimal dimensionality occurred at approximately the preferred walking speed, and increased with faster or slower walking speeds. The dimensionality of trunk motion was also a quadratic function of walking speed for both ML and VT axes (R2 = .81 and .92, respectively). However, dimensionality was highest ($D \approx 5$) at the slowest speed and lowest ($D \approx 4$) at the fastest speed. Dimensionality of trunk motion along the AP axis was not significantly related to walking speed. The effect of walking speed on dimensionality of head motion was significant, but smaller than for the legs and trunk. The particular results depended on the axis assessed. Dimensionality of head motion in the ML axis was lowest at the slowest speed (r2 = .27), while dimensionality of head motion in the AP and VT axes was lowest at the fastest speed (R2 = .46 and R2 = .19, respectively). In summary, only the motion of the knees revealed a benefit of minimal dimensionality at the preferred walking speed. The different effects walking speed has on the dimensionality of movement trajectories of different body parts indicates that the legs, trunk and head are, to some degree, independently controlled during gait.

Mediolateral footpath stabilization during walking in people following stroke.

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Community dwelling stroke survivors most often fall while walking. A previous study (Kao et al, 2014) showed that stroke survivors walked with significantly greater walking instability and step width variability than neurologically intact controls. Understanding how stroke survivors control mediolateral footpath during walking may help elucidate the mechanisms that contribute to walking instability. The objectives of this study are to examine (1) how stroke survivors coordinate lower-extremity joint motion to stabilize mediolateral footpath of the swing leg, and (2) how the inter-joint coordination in footpath stabilization correlates to their walking stability.

We recorded kinematic data on nine stroke subjects and nine healthy controls while they walked on a treadmill at four different speeds. We used the uncontrolled manifold (UCM) approach to investigate the role of inter-joint coordination in the mediolateral footpath stabilization of the swing leg during walking. UCM analysis partitions the variance of kinematic segmental configuration across gait cycles into "good variance" (i.e., the variance component leading to a consistent footpath) or "bad variance" (i.e., the variance component leading to an inconsistent footpath). We quantified walking stability by computing short-term local divergence exponent of the trunk motion, dynamic margins of stability and kinematic variability.

We found that both groups had a significantly greater "good" than "bad" variance ($p<0.05$) for most of the swing phase, suggesting that footpath is an important variable stabilized by the central nervous system during walking. Stroke subjects had significantly greater relative variance difference (i.e., the normalized difference between "good" and "bad" variance) ($p=0.03$), indicating a stronger kinematic synergy in footpath stabilization, compared to the healthy controls. In addition, the kinematic synergy in mediolateral footpath stabilization is strongest during mid-swing but weakest during late swing in healthy gait. However, this phase-dependent strategy is preserved for mid-swing but not for late swing in stroke gait. Moreover, a stronger kinematic synergy in healthy gait is associated with better walking stability whereas having more "good" variance or stronger kinematic synergy in stroke gait is associated with less walking stability. The current findings suggest that walking with too much "good" variance in people following stroke, despite no effect on the footpath, may be detrimental to their walking stability.

Controlling whole body locomotor trajectories in novel environments.

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To create efficient goal-directed locomotor movements, people must be able to control whole body trajectories in novel environments. Yet our understanding of how we plan and execute multi-step walking trajectories is poor. Our purpose was to investigate how people control center of mass (COM) trajectories while walking in a novel environment. Specifically, we challenged COM control by applying a laterally-directed force field to participants' COM during a goal-directed walking task. We hypothesized that when lateral stability is altered by a novel but consistent force field, people would form a predictive model of the environment as evidenced by the presence of after-effects observed in COM trajectories when the force field was unexpectedly removed. 13 healthy young adult participants performed repeated trials of a discrete walking task: 20 Baseline trials (no applied forces), 70 Adaptation trials (in the force field) that included 3 Catch trials (no forces), and 20 Washout trials (no forces). Each trial began with the participant standing in a starting location. After an auditory cue, the participant quickly stepped forward to a target located two leg lengths ahead. During the Adaptation trials, a cable robot applied a laterally-directed force, proportional in magnitude to forward walking velocity, to a waist belt. To evaluate neural control strategies, we quantified an error metric (Signed Area Deviation) relative to a theoretical ideal straight path. When compared to Baseline, during Early Adaptation participants' COM trajectories significantly ($p < 0.01$) deviated laterally in the direction of the applied force field. By the end of the Adaptation period, participants adapted to the field, and trajectories were no longer different from Baseline ($p > 0.05$). During Catch trials when the field was unexpectedly removed, participants exhibited substantial lateral deviations in COM trajectory in the opposite direction of the applied force field ($p < 0.01$). We observed that the novel walking environment initially perturbed COM trajectory during goal-directed walking, and, with practice, they adapted control strategies that restored whole body trajectories to levels similar to baseline conditions. In support of our hypothesis, the presence of after-effects during the Catch trials suggest that people formed a predictive model of the novel environment and used the model to adapt strategies to control lateral motion of the COM during the task. This experimental paradigm will be valuable for furthering our understanding of underlying locomotor control objectives.

Predicting Retention of Locomotor Skill Learning in Virtual Reality and Subsequent Transfer to Overground Walking.

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Obstacle negotiation is an essential skill for community ambulation. Previous studies have demonstrated that goal-oriented obstacle negotiation can be trained on a treadmill with auditory feedback, can be retained after 24 hours, and can transfer to overground walking. Here, we investigate individual differences in learning to determine whether performance improvements during practice can predict retention and transfer to overground walking.

On Day 1, 19 healthy young adults stepped over a single physical obstacle ten times while walking overground (BASE_OG). They then proceeded to step over 140 virtual obstacles viewed via a head-mounted display while walking on a treadmill. In both conditions, participants were instructed to minimize the vertical distance between the foot and the obstacles during the crossing step (foot clearance). The first 20 virtual obstacles were negotiated without auditory feedback (BASE_VR). During subsequent practice (ACQ_VR) participants were given auditory feedback whose frequency scaled with foot clearance. After 24 hours, participants completed one retention block in VR with no auditory feedback (RET_VR). We then assessed overground transfer (TF_OG) in the same manner as BASE_OG. We fit the foot clearance performance curves during ACQ_VR using a mixed-effect, exponential decay model. Multiple regression was used to predict ACQ_VR from BASE_VR performance, and to predict RET_VR and TF_OG from BASE_VR and ACQ_VR performance.

The exponential model provided a good fit to the foot clearance performance curve during ACQ_VR (R2=0.36). A lower collision rate during BASE_VR was associated with greater reduction in clearance during ACQ_VR (R2=0.43, t=-2.19, $p<0.05$). Moreover, a greater reduction in clearance during ACQ_VR (t=3.10, $p<0.01$) and a slower learning rate, estimated by the time constant of the exponential fit (t=-2.45, $p<0.05$), were both associated with larger reductions in foot clearance from BASE_VR to RET_VR (R2=0.61). Lastly, higher BASE_VR foot clearance variability was associated with greater reductions in foot clearance from BASE_OG to TF_OG (R2=0.18, t=2.21, $p<0.05$).

Our study demonstrates that the baseline performance can predict the acquisition and transfer of locomotor skills when trained in VR. We also found that performance during practice influences retention. Overall, initial performance variability may facilitate skill learning and ultimately enhance transfer of learned skills to different environments. Measures of performance variability could also be used as predictors of learning capacity in clinical populations, however further research is required to test this hypothesis.

Dissecting changes in perception following locomotor adaptation.

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Motor adaptation is a form of learning that can improve a movement pattern, but paradoxically can also recalibrate the perception of movement to be inaccurate. This has been demonstrated in walking and reaching: people learn a movement calibration to account for a predictable change in the environment, while simultaneously reducing their perception of the change. Here we describe the dynamic range of perceptual recalibration, and how this relates to the magnitude of motor adaptation.

We studied locomotor adaptation via a split-belt paradigm, where people learn to walk with their legs moving at different speeds (right faster than left). As participants adapt to the split-belt treadmill, they correct their limping gait pattern by learning to take symmetric steps. They also recalibrate leg speed perception so that they perceive their legs to be moving at more similar speeds than they actually are. When the speed perturbation is removed, subjects inaccurately perceive the opposite perturbation (left faster than right). In the first experiment, we studied the time-course of locomotor learning via 3 groups that walked with split belts (at 1.5 and 0.5 m/s) for 3, 15, and 30 minutes. Motor and perceptual changes evolved from 3 to 15 minutes, but then plateaued and did not change from 15 to 30 minutes. Interestingly, the motor and perceptual recalibrations plateaued at different magnitudes: the motor recalibration fully corrected the limp, but the perceptual recalibration only accounted for a portion of the speed difference (~0.4 out of 1.0 m/s difference, or 40%). By the end of adaptation, subjects could walk symmetrically, but still felt perturbed by the split belt environment. Next we attempted to modify the amount of perceptual recalibration by changing the size of the perturbation or how it was introduced. We tested subjects learning a smaller speed difference (0.8 and 0.4 m/s) to see if perceptual recalibration could account for the 0.4 m/s perturbation (same amount as experiment 1), or account for ~40% of it (~0.16 m/s). Results showed the latter, suggesting the perceptual recalibration is a fixed proportion of the perturbation. Finally, we showed that introducing the same speed difference gradually instead of abruptly had no effect on the amount of perceptual recalibration.

Together, these results show that the amount of perceptual recalibration during walking adaptation is proportional to the perturbation size (~40%), develops in 15 minutes, and is not easily modified. Importantly, perceptual learning does not parallel the process of motor adaptation—subjects never fully change their perception despite fully correcting their motor pattern. Supported by NIH NS090610.

Center of pressure divergence during forefoot and rearfoot running.

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Variability is seen as an intrinsic feature of many voluntary actions, allowing the individual the potential to adapt to differing environments and attenuation of unpredicted perturbations in everyday activity. Even such simple actions as walking and running exhibit a degree of variability. However, altered habitual gait patterns can lead to changes in the level of variability. Indeed, alterations in the underlying gait patterns can lead to deviations in movement variability. During running, individuals may choose to adopt a different strike pattern in an attempt to reduce injuries and/or improve performance. Research has reported that adopting a different running style can reduce joint loads in the lower limb although the abrupt switch to a new running style has also been linked to sudden injury.

The aim of this study was to quantify the effect changing running style has on movement variability. Specifically, center of pressure (COP) displacement patterns during each step were quantified using a novel non-linear analysis measure. Nineteen healthy individuals without prior lower extremity injury participated in the study. All individuals were asked to run with their preferred foot strike pattern and two non-preferred foot strike patterns (i.e. forefoot and rearfoot). Using an instrumented treadmill with an inbuilt pressure measurement system, COP displacement paths for each step were recorded over 5 minutes while subjects ran with their foot strike pattern at their preferred pace. Subsequent trials were recorded at the same speed, but with the alternate foot strike patterns. COP displacement from the 3 trials was analyzed using a novel non-linear measure which quantified the rate of COP displacement divergence. Briefly, a nearest neighbor algorithm was created to find the smallest Euclidean distance between the first COP displacement data point and the next nearest data point, excluding the current step of interest. The two points were then tracked throughout the step to determine the rate of divergence. Each data point within each step was used to find an average rate of divergence over the entirety of the 3 trials for each subject.

The results demonstrated that when individuals adopted a rearfoot strike pattern, an increase in the rate and magnitude of COP divergence is observed compared to the forefoot and preferred running conditions. This patterned change in divergence suggests an increase in the exploration of the state space during rearfoot running. Together these findings indicate that utilizing a rearfoot running style leads to increased divergence of the COP over time and therefore increase variability.

Effects of deep brain stimulation on synergic control of actions in Parkinson's disease patients.

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Problems with motor coordination, and stability of movement and posture are among the common consequences of Parkinson's disease (PD). Recently, a theory of synergic control of movements has been developed that allows for objective quantification of stability of movements involving multiple effectors. Previous studies have demonstrated impaired synergic control in PD, namely smaller indices of synergies stabilizing salient performance variables during steady-state tasks (impaired stability) and smaller modulation of synergy indices in preparation of a quick action (impaired agility). We explored effects of deep brain stimulation (DBS) on the synergic control of multi-finger hand and multi-muscle whole body tasks, and the correlation between indices of synergic control across these dissimilar tasks. Ten male PD patients participated in this study. Seven patients had DBS leads in the subthalamic nucleus and three in the globus pallidus internus with disease categorized at Hoehn-Yahr stage II (n = 7), stage III (n = 2), and stage IV (n = 1). Patients performed three main tasks while on their routine oral medications in the DBS-ON and DBS-OFF states: 1) multi-finger accurate force pulse production to a target; 2) whole-body voluntary sway around the ankle joints; and 3) self-initiated release of a load from extended arms. The order of DBS state, and hand and postural tasks were counter-balanced across participants. Five patients were able to perform both hand and postural tasks satisfactorily. Synergy indices were quantified within the spaces of hypothetical motor commands, finger modes, and muscle modes, by quantifying the relative amount of inter-trial variance that kept the task performance unchanged. DBS significantly increased metrics of anticipatory synergy adjustments (reflecting agility) in preparation to quick actions without comparable effects on the indices of stability during steady-state task phases. Data from the five patients who performed both hand and postural tasks were used for across-tasks comparisons. Pearson correlation and ANCOVA analyses confirmed correlations between hand and postural indices of stability and between indices of agility (such as duration of anticipatory synergy adjustments). The results suggest the existence of shared neural mechanisms of synergic control across dissimilar tasks involving different effectors. DBS may benefit quick actions in PD, whereas its effects on action stability are ambiguous, possibly due to adjustments to chronic application of DBS. These contrasting effects suggest that different functional neural subsystems might be involved in the control of action stability and agility.

Shoulder and Elbow Contributions to the Asymmetry of Upper Limb Motion in Patients with Parkinson Disease.

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Asymmetry of upper limb motion is one of characteristic findings in early Parkinson disease. However, there has been unclearness in what anatomical segments mainly contributes and in what clinical features are related with. The aims of this study are 1) to reveal which segment (shoulder and elbow) has more contribution to the asymmetry of upper limb motion and 2) to investigate the relationship between clinical features (tremor and akinetic-rigidity) and asymmetry of upper limb motion.

Participants and Methods: Twenty eight patients with Parkinson disease were included. Of 28 participants, 16 were female and 12 were male. Average age was 67.06 years (standard deviation = 6.76). Participants performed over-ground level walking in the gait laboratory on 8-meter walkway. They repeated self-selected speed walking until minimum of two trials exhibiting appropriate force-plate data were obtained. Ground reaction force (GRF) was obtained from two imbedded force plates with sampling rate of 100Hz. Reflective markers were attached to the pelvis, both lower limbs, the trunk, and both upper limbs. Visual3D software was used for calculating temporo-spatial, kinematic and kinetic parameters. Magnitude of upper limb motion was calculated with anterior to posterior excursion of wrist joint center. Range of shoulder flexion-extension was obtained to investigate the contribution of shoulder to the asymmetry of upper limb motion. Range of elbow motion was calculated with planar angle to avoid the influence of forearm pronation and supination. Formula for symmetry index was 100 x (less affected – more affected) / (less affected + more affected). Participants with symmetry index more than 10% were classified as asymmetric group (vice versa). Participants were classified as akinetic rigid group and tremor group including mixed type. Results: 18 participants were classified as asymmetric group and 10 participants as symmetric group. 16 participants were akinetic rigid group and 12 participants were tremor group (table 1). For asymmetric group, symmetry index of shoulder and symmetry index of elbow could explain 81.15% of variance of symmetry index of wrist joint center motion ($p<0.01$). Simple regression for the influence of symmetry index of shoulder explained 78.65%. Simple regression for the influence of symmetry index of elbow explained 31.37%. Between asymmetric group and symmetric group, there were no significant differences in HY stage, HPDR score, tremor score and non-tremor score (table 2). Asymmetric group had lower correlation coefficient between shoulder and elbow in more affected limb ($r =0.65$) than symmetric group ($r = 0.80$). Compared to akinetic rigid group, tremor group showed tendency of larger symmetry index of wrist joint center and shoulder ($p = 0.08$). Conclusion: Upper limb motion asymmetry in sagittal plane attributes largely to the asymmetry of shoulder motion. Clinical phenotype of tremor may have relation with upper limb motion asymmetry. Further study with larger sample size should be performed to confirm above results.

"A Novel Rehabilitation Strategy for Affected Upper Limb in Hemi-Parkinson Using Cross-Education and Mirrored Sensory Feedback: Case Study".

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The majority of patients affected by upper limb hemiparesis remain with severe motor disability, despite all rehabilitation efforts. Consequently, extensive clinical research is dedicated to develop novel strategies aimed to improve the functional outcome of the affected limb. Although repetitive voluntary physical practice is beneficial, it is extremely challenging following neurological insult, in which voluntary control of the affected limb is very limited or absent altogether. Therefore, finding alternatives to voluntary physical movement as a means for improvement in motor skill performance is of great importance. We have recently developed a novel training tool that is based on sensory signals and cross-education in which we exploit the voluntary control of one hand to train the other. The subjects actively performs a sequence of finger movements with one hand while receiving visual feedback as if the opposite hand is performing the movement. In addition, the opposite hand is passively moved in a corresponding manner by a robotic device. Thus voluntary control of the affected hand is not required. In healthy subjects, we reported that the combination of passive movement and manipulated visual feedback result in significant performance gains. The aim of the current study was to expand these results from healthy subjects, to examine the utility of this training setup in the context of Hemi-Parkinson rehabilitation. We present behavioral gains accompanied by changes to functional magnetic resonance imaging dynamics following treatment with this setup in the case of patient LA, a young man with significant unilateral upper-limb dysfunction stemming from hemi-parkinsonism. LA underwent daily 1-hour intervention for two weeks in which he actively trained the non-affected upper limb, while receiving online sensory feedback that created an illusory perception of voluntary movement in the affected limb. Improvement in motor capacity of the affected limb was accompanied by enhanced activation in the pre-frontal cortex and by a widespread increase in functional coupling in the brain.

The regularity of the COP signal in quiet stance in Parkinson's disease patients.

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Parkinson's disease (PD) is a neurodegenerative disease, which is characterized by tremor, muscle rigidity and bradykinesia, what may affect the posture and the body balance. The dynamical structure of postural sway during quiet standing, especially its regularity was recently found to be related to the amount of attention invested in postural control (Stins et al., 2009). The regularity of the COP signal was quantified on the basis of sample entropy (Richman et al., 2000) and the automatic postural control processes increase the sample entropy, while volitional control decreases it (Roerdink et al., 2011). Some authors observed more regular COP signal in clinical groups compared to healthy controls (Donker et al., 2008, Roerdink et al., 2006).Therefore, the aim of the study was to assess the COP signal regularity using sample entropy in patients with Parkinson's disease.

The research was conducted on 17 patients with PD at stage III (age: 66±6,6 years; body mass: 76±12,6 kg; height: 168±5,4 cm) and 17 older healthy adults (age: 70,2±4,8 years; body mass: 72,8±7,7 kg; height: 164,1±8,0 cm). The procedure consisted of quiet standing with open eyes (OE) and closed eyes (CE). Each trial lasted 30s and was repeated three times. We analyzed the velocity (v) of COP [cm/s], range of COP displacement [cm], root mean square (rms) COP [cm] and sample entropy.

The values of sample entropy in open eyes was significantly lower ($p = 0.021$) in the PD group compared to the control group. Also in closed eyes the sample entropy was lower in the PD group, whereas these differences was not significant ($p = 0.360$). In both open and closed eyes the data showed significantly higher values of the measured parameters of range COP (EO: $p = 0.009$, EC: $p = 0.0404$), rms COP (EO: $p = 0.003$; EC: $p = 0.028$) and insignificantly higher v COP (EO: $p = 0.070$; EC: $p = 0.691$) in the PD compared to the control group.

Lower values of sample entropy in the PD group suggest the more regular COP signal, which indicates the less automatic postural control. The PD patients have to invested more attention in postural control than healthy subjects.

Fall risk prediction in Multiple Sclerosis using postural sway metrics.

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Background: Balance impairment affects over 75% of individuals with multiple sclerosis (MS) during the progression of the disease, and often leads to increased risk of falling. Numerous postural sway metrics have been shown to be sensitive to balance impairment in individuals with MS. Yet there is limited data to inform guidelines on the most appropriate postural sway metrics for impairment tracking and fall risk evaluation. This investigation assessed the accuracy and feature importance of various postural sway metrics to differentiate MS individuals as a function of physiological fall risk.

Methods: This secondary data analysis included 153 participants (50 controls and 103 individuals with MS) who underwent balance assessment (30s eyes open standing on a force platform) and physiological fall risk assessment (Physiological Profile Assessment - PPA). Participants were further classified into four subgroups based on fall risk: controls (n=50, 64.9 ”Ą 4.9 years old, PPA < 1); low-risk MS (n=34, 54.0 ”Ą 13.1 years old, PPA < 1, EDSS: 4.3 ”Ą 1.5); moderate-risk MS (n=27, 58.3 ”Ą 8.3 years old, 1 ”Ü PPA < 2, EDSS: 5.3 ”Ą 1.5); high-risk MS (n=42, 56.8 ”Ą 9.7 years old, PPA ”Ż 2, EDSS: 6.0 ”Ą 0.9). Twenty common sway metrics were derived following standard procedure, and subsequently used to train a machine learning algorithm (random forest ØC RF, with 10-fold cross validation) to predict individuals”Æ fall risk grouping. The feature importance from the RF algorithms was used to select the strongest sway metric for fall risk prediction.

Results and Discussion: The sway-metric based RF classification accuracy was high in discriminating controls from MS individuals (> 84%), and moderate discriminating low-risk MS individuals from high-risk individuals (72.3%). Sway sample entropy, a sway regularity metric, was identified as the strongest feature for classification of low-risk MS individuals from healthy controls. Whereas for all other comparisons, the mediolateral sway amplitude was identified as the strongest predictor for fall risk groupings. These findings set the foundation for the development of guidelines for accurate assessment of balance impairment in individuals with MS.

Chewing speed appears resistant to age-related neuromotor decline.

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A general slowing of motor function is a typical part of the aging process. A decreased ability to exploit speed in their movement strategies is due to gradual structural changes in nerve and muscle tissues as people age. The aim of the study was to examine whether chewing rates demonstrate a level of decline similar to other motor tasks. Fifteen young (20-40 years of age) and fifteen healthy older adults (over 60 years of age) participated in this study. Individuals completed a battery of motor tasks including: walking, finger tapping, simple reaction time, postural sway, and chewing. Gait metrics were collected using a 20-foot pressure sensitive walkway and accelerometers attached to the foot, low back, and head. All walking trials were performed at an individual's preferred speed. Finger tapping rates were measured using an accelerometer affixed to a table, and all participants tapped at a preferred and maximal rate. Upper extremity reaction time was recorded by depressing a mouse button with an associated timing mechanism, whereas a similar foot pedal interface was used to measure lower extremity reaction time. Postural sway and center of pressure data was collected using a force plate. Surface EMG of the masseter was used to record fast(2Hz), slow(1Hz), and preferred chewing rates. Fast and slow chewing rates were set using an auditory metronome which was switched off during recording. Age comparisons for each task were performed using general linear modeling, with additional considerations for chewing speed effects and interactions for the chewing task. Preferred walking speed, as well as preferred and maximal finger tapping speeds were comparatively slower ($p<.05$) for older adults. Simple reaction time was longer($p<.05$), indicating slower responses, for the older adults compared to the young adults. Slowing of postural sway and increased excursion ranges were also characteristic of the older adults compared to their younger counterparts. Chewing speed did not differ between age groups across all chewing conditions ($p>.05$). Results reveal that older adults demonstrate a gross slowing of movement apart from chewing speed which appears to be preserved with aging. Preservation of chewing rates compared to other motor tasks may be due to the difference in anatomical innervation between muscles of mastication and the limbs. Masticatory muscles receive bilateral innervation including ipsilateral and contralateral inputs from the motor cortices, whereas limb muscles receive mainly unilateral innervation from the contralateral cortex. The neural redundancy may preserve chewing rates despite age-related degradation of the system.

Laryngeal vibro-tactile stimulation for spasmodic dysphonia: effects on voice quality and its neural correlate over somatosensory-motor cortex.

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Spasmodic dysphonia (SD) is a voice disorder resulting in involuntary spasms of the laryngeal muscles leading to voice breaks and a strained or strangled voice quality interfering with speech. There is no cure for SD. Evidence indicates that somatosensory processing is impaired in SD. This study addresses the question, if somatosensory processing in SD can be modulated through vibro-tactical stimulation (VTS) to normalize pathological speech.

METHOD: This study evaluated the effect of cutaneous laryngeal VTS on the improvement of voice quality in SD patients (N=10). VTS was applied through small, wearable low voltage vibro-motors bilaterally attached to the skin over the laryngeal area (human voice box). Standard voice quality assessment tests were performed pre- and post-VTS. Based on the acoustic signals captured during vocalization with and without VTS, the number of voice breaks and cepstral peak prominence (CPP) were determined. CPP is a prominent measure of voice quality and a reliable predictor of dysphonia. EEG over the somatosensory and motor cortical areas was recorded to obtain neural correlate data of VTS.

RESULTS: 1) VTS induced measurable improvements in voice quality in 8/10 patients as indicated by a reduction in the number of voice breaks and a prominent rise CPP. 2) Compared to controls, SD participants exhibited higher levels of theta- and alpha-band oscillatory activity over laryngeal somatosensory and motor cortical areas during vocalization. 3) These heightened levels of cortical activity declined as more VTS was applied.

DISCUSSION: Our finding confirms that low-frequency cortical hyper activity is present in SD – a feature common with other forms of focal dystonia. The reduction in voice symptoms was associated with a decline in low-frequency cortical hyper activity. This cortical effect has been observed in cervical dystonia patients as they successfully applied a sensory trick (a tactile maneuver alleviating abnormal contractions). Thus, laryngeal VTS in SD may activate the same neurophysiological mechanism underlying effective sensory tricks, which can lead to meaningful improvements in voice quality of SD patients.

Development of overarm throwing in children, adolescents and young adults.

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Introduction: The throwing involves a sequential and continuous action of body segments that progressing from less skilled to a more refined and harmonic actions. Considering the transition between ages, it is relevant to study and understand the development of throw in the mature stage. Objective: To compare the throwing movement in children and adolescents during acquisition and improvement of the mature stage of throwing with adults. Methods: It is a prospective, cross-sectional study with a sample of 15 children (5-7 years), 15 adolescents (11-13 years), and 15 young adults (20-25 years). The three-dimensional kinematic analysis was used to describe spatial trajectories of 6 markers attached on anatomical landmarks of upper extremity and trunk. The experimental protocol consisted of 10 throwing attempts with focus on force. The motor control during throwing was evaluated by strategy and space-time kinematic variables (hand trajectory, acromion trajectory, time, mean velocity, displacement of left and right posterior superior iliac spines (PSIS) and the trajectory/upper limb length ratio - TLR) during the cocking and acceleration phases of throw. ANOVA with repeated measurements and the Bonferroni multiple comparisons were used for statistical analysis. Results: Adults showed greater scores for movement strategy than children, indicating more mature throw. In the cocking phase, children showed lower angle of elbow flexion than adolescents, and adults showed greater hand and acromion trajectory, time, and left and right PSIS displacement than children and adolescents. In the acceleration phase, adults showed greater angle of elbow flexion , mean velocity, and lower time and TLR than children and adolescents. Children showed greater right PSIS displacement than adults and adolecents. Conclusion: Kinematic parameters of throwing in children showed an immature movement strategy, resulting in poor motor control during throwing . Children are acquiring mature throwing pattern of movement while adolescents were refining it.

Key words: children, kinematics, child development, motor skills, shoulder.

Muscular activity and motor strategy of overarm throwing during development.

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Fundamental motor skill as throw serves as base of more complex movements required during motor development. Throwing has phases of execution characterized by different types of movements. The electromyography (EMG) activity during throwing is well known in athletes. However, until now there are not found studies about EMG during overarm throw considering the developmental background. Purpose: To analyze throwing EMG and motor strategy during development in the cocking and acceleration phases of throwing. Methods: Particpants were 15 children 5-7 years (CH group), 15 adolescents 11-13 years (AD Group) and 15 young adults (YA Group). Subjects were instructed to perform 10 overarm throws focusing on force. EMG was sampled of serratus anterior (SA), upper (UT), middle (MT) and lower trapezius (LT), and middle (MD) and anterior deltoid (AD). EMG was represented by mean values of root mean square (RMS) in each phase of throw normalized (NEMG) by 95% of maximal activity. To analyze muscle modulation, muscles were divided in postural and focal muscles. Analyses were done for cocking and acceleration phases. Motor strategy scores were established based on the performance criteria of Test of Gross Motor Development-2. Results: CH group showed greater values of SA NEMG than AD group, and greater NEMG of all muscles compared to YA group. AD group showed greater NEMG for all muscles compared to YA group, except for AD muscle in the cocking phase. CH group showed greater UT and MT NEMG than AD group. AD group showed greater NEMG of UT, MT, LT and MD in the acceleration phase than YA group. Results of modulation showed that CH group showed greater modulation of postural muscles compared to AD group, and greater modulation of postural and focal muscles compared to YA group. AD group showed greater modulation of postural and focal muscles compared to YA group in the cocking phase. At acceleration phase, CH group showed greater modulation of postural and focal muscles compared to AD group; AD group showed lower modulation of postural and focal muscles compared to YA group. The results of motor strategy showed that YA group is the only one that doesn't fail on criterions that characterize mature throw. Conclusion: Although expected, CH and AD group not showed full mature motor strategy. Moreover, differences in the NEMG among groups can suggest a search for shoulder stability while the task is done, mainly in younger groups when is more evident the greater demand for shoulder stability.

Anatomical and functional characterization of brain injury subtypes in children with unilateral cerebral palsy: An atlas-based analysis.

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Purpose— despite having a unitary diagnosis, children with unilateral cerebral palsy (UCP) display strikingly different manual abilities. Variability in hand function among children with UCP might reflect in part, differences in underlying etiology—particularly the type of brain injury and resulting anatomical sequelae. The purpose of this study was to use atlas-based analysis of structural images to determine whether children with periventricular (PV) versus middle cerebral artery (MCA) injuries might exhibit unique anatomical characteristics that account for differences in hand function.

Methods—Forty children with UCP (PV=27, MCA=13, age 9.1-±3.1y) underwent structural (T1-weighted) brain imaging using 3T MRI. Brain lesions were classified as PV or MCA. Images were normalized using a linear transformation, followed by large deformation diffeomorphic metric mapping on MRICloud (Johns Hopkins). Whole brains were parcellated into 289 structures (ROIs). Volume estimates were obtained for each ROI. Hand function was assessed using the Jebsen-Taylor Test of Hand Function (JT), Box and Blocks test (BB), and the Assisting Hand Assessment (AHA). An unbiased, differential expression analysis was performed to determine volumetric differences of individual ROIs between PV and MCA groups. Next, a principal component analysis (PCA) was performed with ROIs that significantly differed between the two groups. The top 3 principal components were extracted and used for principal components regression to predict hand function.

Results—Univariate tests indicated children with PV lesions had significantly better hand function scores than children with MCA lesions in the BB ($p<.01$), JT ($p<.001$), and AHA ($p<.05$). For imaging data, the differential expression analysis revealed 48 structures that significantly differed between PV and MCA—30 were decreased and 18 increased in volume for MCA relative to PV. PCA extracted anatomical components that comprised the two types of brain injury. In the MCA group, reductions of volume were concentrated in sensorimotor structures of the injured hemisphere. Principle component regression indicated that the first two principal components significantly predicted hand function with $R2=.42$, $F(3,36)=8.8$, $p<.001$ for JT, $R2=.39$, $F(3,36)=7.7$, $p<.001$ for BB, and $R2=.36$, $F(3,36)=5.9$, $p<.01$ for AHA.

Conclusion—Our results highlight unique quantitative differences between brain injury types in children with UCP that also predict differences in hand function. The systematic characterization of anatomical patterns and their relation to hand function could help establish precise assessment of functional prognosis.

Effect of time of brain injury on the expression of the flexion synergy in pediatric hemiplegia.

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Introduction: Unilateral brain injury before, during, or soon after birth resulting in pediatric hemiplegia (PH) causes movement impairments on one side of the body. One clinically observed impairment is the upper extremity flexion synergy, an involuntary coupling between shoulder abduction (SABD) and elbow, wrist and finger flexion. Previous work with adults after a stroke has demonstrated that increased activation of SABD results in an increased expression of the flexion synergy however less is known about these involuntary coupling patterns in the PH population. The aim of this study is to quantify the flexion synergy by measuring reaching ability as a function of SABD load in PH. It is hypothesized that individuals with earlier injuries (PRE) will be able to reach farther at higher SABD loads compared to those with later injuries (PERI and POST) due to available neural pathways for upper extremity control. Methods: Participants completed a set of reaching tasks in the Arm Coordination Training 3-D, an admittance controlled haptic robot. Participants were instructed to reach forward towards a virtual target set near full arm extension. Each set of reaches required participants to lift their arm against different loads including full support on a haptic table and 20%, 35%, 50%, 65% and 80% of maximum SABD torque generation ability. Reaching ability was quantified as a reach distance deficit defined as the percent change between the overall max distance achieved and the max distance for each load level. Results: A total of eight participants (ages 11y-19y) completed this study with two typically developing (TD) controls and two individuals in each injury timing group. The mean reach deficit at 20% maximum SABD torque was -4±6% (TD), -4±5% (PRE), -7±3% (PERI), and -11±15% (POST), and at 80% maximum SABD torque was -17±16% (TD), -7±2% (PRE), -8±16% (PERI), and -76±33% (POST). These preliminary results show a decrease in reaching ability at higher load levels with trend towards greater deficits in the latest injury timing group compared to earlier groups. Conclusions: Use of retained ipsilateral corticospinal projections may enable the relative maintenance of reach ability seen across load levels in individuals with earlier unilateral brain injuries. In contrast, a reliance on more diffuse reticulospinal projections may explain the decreased reach ability seen in later injuries. Continued investigation of flexion synergy presentation with this population will incorporate novel motion capture technology to measure hand opening and a pressure mat to measure grasping forces during functional reaching/grasping in this same population.

The Relationship of spatiotemporal kinematics of upper extremity movement and motor development in young infants.

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Background: Coordinated movement of the upper extremities in infants is critical for interaction with the environment. Kinematic analysis of upper extremity movement can provide insight on spatial and temporal variables that may influence motor development. To the best of our knowledge, a relationship between spatiotemporal kinematics and motor development, measured by clinical outcome tools, have not been studied. The purpose of this study was to investigate the relationship between movement, as measured by 3D spatial and temporal kinematics of the upper extremity, and motor development, as measured by the gross motor (GM) and fine motor (FM) subtests of the Bayley Scales of Infant Motor Development, 3rd Edition (Bayley).

Methods: 11 healthy infants participated in this longitudinal, prospective study 2 – 4 sessions for a total of 187 trials. Passive markers were placed on the infant's hands and movement was recorded in supine with a 10-camera Vicon Nexus 3D motion capture at 120 Hz for 6 to 12, 30-second trials. The Bayley was administered measure motor skills. Data was processed using MATLAB and regression analysis was completed using STATA software.

Results: Multiple regression analyses were used to determine the relationship between spatiotemporal variables and score on the Bayley subtests. Age was included in all models. GM score was significantly predicted by spatial variables (mm) including movement displacement (p=046), movement length (p=.014), and arc length (p=.042), holding all other predictors in the model constant. Conversely, FM score was significantly predicted by temporal variables including movement/minute (p=.037), average movement speed (mm/s)(p=.026), and peak velocity (mm/s)(p=.048), holding other predictors constant. There are no significant spatiotemporal variable predictors in the combined Bayley score model (GM and FM).

Discussion: This study provides insight on how spatiotemporal kinematics of the upper extremity relate to clinical assessment tools used to describe motor development. The results from this study suggest that improved GM score is significantly associated with movement displacement, movement length, and arc length (or smoother trajectory). Improved FM score is significantly associated with number of movements/minute, average movement speed, and peak velocity. The results of this study could be used to help target and shape rehabilitation interventions designed to improve upper extremity function and coordination.

Quantitative assessment of sensorimotor control in humans with GNAO1 gene mutations: a case study.

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A mutation in the GNAO1 gene causes epileptic encephalopathy and disordered movement. This gene codes for the alpha-subunit, o, of the heterotrimeric G-protein Go which is found in synapses in the CNS and modulates presynaptic signaling and autoinhibition. This disorder is extremely rare, with approximately 50 reported cases worldwide. Patients with certain mutant alleles present with choreatic or ballismatic movements in the absence of seizures, in addition to hypotonia and motor developmental delay. Further, qualitative reports suggest a progression of disordered motor symptoms as patients age. Our objective was to quantitatively explore the neuromotor control characteristics in a patient with a GNAO1 mutation-related movement disorder. Following parental consent and a clinical neurological examination, we measured upper limb goal-oriented reaching, dexterity, gait, balance, reaction time, and leg strength in a 12-year old female with a heterozygous p.Ile344del mutation in GNAO1. She, together with a healthy age-matched female as a control, participated in six behavioral tasks. First, participants reached for objects with either the left, right, or both hands while their movements were tracked using a motion capture system. Kinematic variables including movement velocity, trajectory straightness, and jerkiness were measured. Then, using the Purdue Pegboard task, participants' manual dexterity was tested for bimanual, dominant unimanual, and nondominant unimanual conditions. This is a test of fine motor control with which we can compare participants' data with established norms. To assess gait, we measured body segment kinetics and kinematics while the participants walked in a straight line. To test balance, we measured the center of pressure variability on a force plate while the participants used either a two-foot or one-foot base of support stance. Participants' leg strength was tested using a biodex dynamometer, measuring quadriceps strength through isometric leg extension. To measure reaction time, we used a dual-choice reaction time task; participants pressed specified buttons corresponding to a presented stimulus on a computer screen. Results show impairment and greater variability in all sensorimotor control tasks. Furthermore, the patient shows lateralized patterns of impairment, suggesting asymmetrical presentation of movement disorder phenotype. To our knowledge, these deficits have never been quantitatively studied in this disease. Results from this study will help quantify motor deficits in GNAO1 patients and guide more specific studies investigating sensorimotor control deficits related to GNAO1 mutations.

Deficits in subtle motor function persist at clinical recovery in teenagers with concussion.

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Objective: To use the Physical and Neurological Examination of Subtle Signs (PANESS) and evaluate its sensitivity to residual motor changes in teenagers 13-17 with sports-related concussion.

Methods: 15 teenagers (5 females) with sports-related concussion were evaluated during the sub-acute stage of injury (4-14 days) and at the point of clinical recovery (43-101 days post-injury) with the PANESS. Comparison PANESS performance data were acquired from 20 age and sex-matched controls with no history of concussion, who were evaluated at 2 distinct time points (visits were ~1 month apart). Main effects of group, time, and interaction effects were evaluated with an analysis of covariance which controlled for socioeconomic status.

Results: In the sub-acute stage of injury, teenagers with concussion had significantly poorer PANESS performance than controls. Furthermore, at the point of clinical recovery, teenagers with recent concussion continued to have significantly poorer performance than controls. Within the concussion group, performance improved between visits, as evidenced by significantly poorer performance in the sub-acute stage of injury compared to performance at clinical recovery. Importantly, among control participants, PANESS performance was consistent between time points.

Conclusions: Collectively, we found that the PANESS is sensitive to subtle motor deficits after concussion, can identify significant improvements in deficits, and is able to consistently identify the absence of deficits in never-concussed teenagers. Future studies should examine PANESS performance in conjunction with other markers of injury (e.g. neuroimaging findings) to facilitate an enhanced understanding of sports-related concussion and recovery.

Head-acceleration during experimentally induced falls as a function of age.

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Background: Traumatic brain injury (TBI) is a major cause of morbidity and mortality in older adults. Upwards of 80% of TBI in older adult stems from the head hitting the ground or other surface during a fall. The elevated rate of fall-related TBI in older adults may stem from age-related differences in fall mechanics. Yet there is limited information concerning the kinematics of the head during falls as a function of age. This current investigation sought to examine kinematics of head impact during an experimentally induced sideway fall in healthy young and older adults.

Methods: 33 (16 young adults (3 females) and 17 older adults (3 females)) participated in an experimental fall paradigm. Young adults were on average 21.6 years (SD2.6) and older adults were on average 63.6 years (SD 5.1). Participants underwent three experimentally induced sideway falls. Subjects were made to fall by releasing a tether that supported the participants at a 10° leaning angle in a standing position. A ten-camera motion capture system (VICON, Oxford metrics) tracked five reflective markers attached to the head at a sample rate of 100 Hz to collect kinematic data of the head. Head acceleration was computed by numerical differentiation of head velocity and subsequently filtered with a cutoff frequency of 20Hz. Maximum head acceleration during a fall was calculated with a custom code in Matlab. The maximum head acceleration was placed in a 2 (age-group) by 3 (trial) mixed model ANOVA.

Results: Data from a total of 99 falls were recorded and analyzed. Overall, head acceleration ranged from 1.4 to 21.5 g with an average of 4.8g (SD 3.9). Young adults had an average head acceleration of 4.4g (SD 2.6) while older adults had an average acceleration of 5.2g (SD 4.4). Statistical analysis revealed an interaction between age group and trial [$F(2,62)=3.9$; $p < 0.05$). It was observed that age-related differences in head acceleration were greatest in the first trial (3.7 vs. 5.7g) and were minimized with exposure.

Discussion: The main observation of this investigation was that healthy older adults have greater head acceleration during experimental induced falls especially in the first trial. It is logical to speculate that elevated head acceleration in older adults results from age-related changes in the neuromuscular system. However, the observation that age-related differences were mitigated over three trials highlights that an alteration in control strategy is the likely mechanism. It remains to be seen if interventions targeting head control can reduce older adults' fall-related TBI risk.

The efficacy of active rehabilitation versus standard rest protocols in recovery from concussion in adolescents and adults: an updated systematic review.

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Objective: Systematic review to determine the effectiveness of active rehabilitation protocols in accelerating recovery from concussion compared to the standard rest protocols with gradual return to activity.

Data Sources: PubMed, Old Dominion library databases, Cochrane Library, and PsychBite entries dated 2013 to December 2017 were searched using the search terms concussion, mild traumatic brain injury, recovery, active rehabilitation, standard rest, standard of care, active rehabilitation, and exercise.

Study Selection: Included studies must provide a comparison in standard rest protocol versus a form of active rehabilitation and assess the impact of each on recovery from concussion. Studies assessing more severe forms of traumatic brain injury (skull fracture, hemorrhage, etc.) as well as concussion were excluded.

Data Extraction: Outcome data consists of Post-Concussion Symptom Scale (PCSS) score, days from initial injury to recovery, and self-reported symptom assessments, cognitive assessments and physiological assessments (fMRI). Risk of bias and quality was assessed by two reviewers.

Results: Five studies were included for this review after database searches yielded 779 results. Aerobic exercise following concussion is indicated to provide greater symptomatic relief assessed via PCSS, enhanced cerebral perfusion assessed via fMRI throughout the recovery process, and fewer average days to achieving medical clearance compared to rest. More frequent bouts of aerobic exercise when performed below but near symptomatic threshold for heart rate are indicated to be associated with more efficient recovery from concussion compared to standard rest protocols. Cognitive exercises for rehabilitation from concussion do not seem to provide additional benefits compared to rest.

Conclusion: Aerobic exercise appears to provide cognitive and physiological benefits while accelerating recovery from concussion compared to standard rest protocols. Future research needs to be dedicated to determining the optimal intensity and frequency of aerobic exercise regimens during the rehabilitation process for concussion.

Augmented reality ADL assistance in Alzheimer's disease.

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Introduction

Alzheimer's disease (AD) can impair activities of daily living (ADL) and therefore limits independent living. In this study, we investigated the feasibility and usability of an AR approach to assist AD patients in the daily task of tea making.

Methods

We tested ten AD patients (71.8±11.1a) in the ADL of tea making in a crossover study, with each one trial of a natural execution and the Therapy Lens condition (TL). In the TL condition, patients wore the Microsoft HoloLens headset showing holographic animations of the next necessary action step, triggered by the voice command "next". Parameters were the trial durations, the success of achieving the task goal, and the number of errors. Semi-structured interviews served to evaluate the systems usability.

Results

In the TL condition, three patients failed ($p=.25$) and trial durations were significantly longer than in the natural condition (77.1s±23.2s vs. 111.3±24.1s). rmAnovas revealed differences for trial durations ($p=.02$, Glass' $\Delta=1.5$), but not for errors ($p=.89$). A model of multiple linear regression (MLR) for the relative difference of trial durations between the two conditions revealed an R^2adjusted of .96 ($p<.01$), with an impact of errors in the natural ($\beta=-.86$, $p<.01$) and a moderation by errors in the TL condition ($\beta=-.361$, $p=.01$). More errors in the natural conditions therefore predicted smaller relative differences between the conditions. Qualitative content analysis revealed that 60% of the patients were unsatisfied with the hardware dimensions, 90% were able to control the application via voice commands, and overall acceptability was mixed with ratings ranging from "helpful" to "not required".

Discussion

The TL application in its present form has to be considered as a secondary task, increasing the demands of the overall task. However, regression analysis suggested that in patients with more severely impaired performance the secondary task costs were almost balanced by the benefits from the given AR support. Interviews underline that the, mainly hardware, constraints still preponderate the given assistance. Future hardware advances have the potential to significantly help patients with ADL impairments.

Effect of 8-week aquatic exercise program on static and dynamic balance in the children with hemiplegic cerebral palsy.

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The aim of this study was to investigate the effect of 8 weeks of aquatic exercise on the static and dynamic balance of children with hemiplegic cerebral palsy. The population of this study was 8 to 10 years old children with cerebral palsy spastic hemiplegia without mental disabilities. Thirty subjects were selected with available and targeted sampling method and randomly assigned to intervention and control groups (each including 15 children) base on a pre-test. Subjects in the intervention group participated in an aquatic exercise program for 8 weeks, 3 sessions per week. The control group did not participate in any of these exercises and continued their daily activities. Postural control was evaluated using Biodex Balance SystemTM in the significance level of $P < 0.05$. The results showed a no significant difference between pre and posttest of static balance in control group. But, there was a significant difference between pre and posttests of static balance (in both anterior-posterior and medial-lateral) in the experimental group. Unlike the experimental group, there was no difference between pre and posttests of the control group in dynamic balance. Also, there was a significant difference between two groups in dynamic balance. Overall, it was observed a significant effect of aquatic exercise on static and dynamic balance in children with cerebral palsy. It is recommended to use aquatic exercise as a helpful intervention for children with cerebral palsy.

Keywords: Aquatic exercise, Biodex, Children, Hemiplegia, Static and Dynamic Balance

Visuomotor pursuit tracking using Opti-Speech, an interactive EMA system

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Visuomotor pursuit tracking (VMT) tasks can provide an understanding of the processes involved in speech motor planning and execution. Results from speech VMT experiments have helped investigators gain insight into speech motor control for both healthy individuals and persons having apraxia of speech (AOS). Most of this research has focused on examining lip and jaw motion while participants follow sinusoid motion visually presented on a computer monitor. Less is known about the specific motor control properties of the tongue, the primary speech articulator. The current study examines the tracking capabilities of the tongue using "Opti-Speech," an interactive 3D electromagnetic articulography (EMA) system. Movement data were collected from ten healthy participants. Streaming EMA data from five lingual sensors were used to construct a real-time image of the participant's tongue, shown on a computer monitor. The participants were instructed to watch a virtual, moving, intra-oral spherical target and to track its movement using their tongue tip sensor. The target (12 mm in diameter) was programmed to move in a sinusoidal direction and was varied in frequency (0.4, 0.6, 0.8 Hz), direction (vertical, lateral, horizontal), and predictability (predictable, unpredictable). When the tongue tip sensor was placed within the coordinates of the spherical target, the target changed color from purple to green, providing real-time feedback concerning tracking performance. Preliminary analyses (Pearson correlation coefficients) indicate that tracking accuracy is reduced with increasing target speed (frequency), while amplitude ratio data suggest that tracking accuracy is higher in the lateral direction than in the vertical and horizontal directions. Despite predictions that target unpredictability would result in lower tracking accuracy, this pattern was not observed: frequency-modulated targets were tracked with similar accuracy to the 0.8 Hz targets. Suggested explanations for these findings will be offered, and implications for studying individuals with speech motor planning disorders will be discussed.

The comparison of two water-based & land-based exercises on balance and mobility in elderly women with Parkinson disease.

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There is a lot of evidence about the positive effect of physical activity on the complications and problems of Parkinson's disease, but it has been difficult for these patients to perform these types of exercises in dry conditions. Some researchers have introduced physical exercises in the water environment as one of the suitable alternatives for these individuals. Exercise in the water environment, due to the physical benefits of water, such as flotation and hydrostatic pressure, is likely to give the elderly an opportunity to work physically in a safe and painless environment. The purpose of this study was to compare the effectiveness of two water-based & land-based exercises on the balance and mobility of elderly patients with Parkinson's disease. In this quasi-experimental study, thirty-seven women (aged 55-67 years old) with Parkinson's disease categorized in stages 1-3 on the Hoehn and Yahr Staging Scale were randomly assigned into three groups of control (n=10), water (n=13), and dry land (n=14) exercises. From all three groups, the pre-test and post-test were used in Berg balance scale (BBS), timed up-and-go (TUG) and functional reach test (FRT). Both exercises were performed for 8 weeks, two days a week and 90 minutes each session.

The results of one way ANOVA at the significant level of 0.05 showed that both exercises had significant effects in two groups, but no significant difference was observed in the control group. Also, the results showed that there was a significant difference between two exercise methods in water and in the dry land so that the performance of the water-based exercise group in all three tests was better than that of the land-based one.

Keywords: Balance, Elderly, Land-based exercise, Mobility, Parkison disease, Water-based exercise

Left-handers are more asymmetric than right-handers in reaching tasks.

Authors: Jiali Liang, Krista Wilkenson, PhD, Robert Sainburg, PhD OTR.

95. Comparison of reach-to-grasp movement kinematics in real and virtual reality environments

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Virtual Reality (VR) offers unprecedented opportunity as a scientific tool to study visuomotor interactions, training, and rehabilitation applications. However, it remains unclear if performing hand-object interactions in VR, which often lacks haptic feedback, may differ from those performed in the real world. We therefore sought to establish the degree to which reach-to-grasp movement kinematics remain invariant whether they are performed in a Real or VR environment.

We examined reach-to-grasp kinematics in 15 healthy right-handed subjects (3F, 23.5 ±6.4 years old) following informed consent. Motion capture recording of markers attached to the index and thumb tips was used to drive a virtual finger tips in a custom VR environment developed in Unity, and projected to the subject using a head mounted display.

Subjects were instructed to reach-to-grasp-to-lift a small, medium, or large rectangular object at a near, medium, or far position (9 conditions, 12 trials/condition) in response to an auditory cue. In the REAL environment, glow in the dark objects were used. In the VR environment, virtual objects were used (matched in size and location). Contact with the virtual objects was based on a custom collision detection algorithm taking into account the thumb and index tips and the corresponding object surfaces. Differences between the environments were evaluated by comparing aperture and transport velocity profiles, peak aperture, time to peak aperture, peak transport velocity, and time to peak transport velocity.

Correlations between REAL and VR transport velocity ($r = 0.99 \pm 0.00$, $p < .01$) and aperture ($r = 0.97 \pm 0.01$, $p <.01$) profiles, averaged across subjects and conditions, indicated largely invariant movement patterns. A 2 x 3 x 3 rmANOVA with factors Environment (REAL, VR), Object Size (small, medium, large), and Object Distance (near, middle, far) indicated significant main effects of Size for aperture measures, and Distance for transport measures, as would be expected. There were also a few main effects of Environment and Size x Environment interactions for specific variables. In summary, our findings suggest that reach-to-grasp movement patterns are largely similar in VR and Real environments, though small albeit significant differences do exist in some specific variables. These differences were portrayed by significant interactions between the Environment and Object Size factor (than the Distance factor), indicating the potentially important aspect of accurate collision detection algorithms. These data are discussed with respect to reach-to-grasp coupling and implications for haptics-free VR for neurorehabilitation.

96. Electroencephalography power in infants at risk for developmental delay across the first half year of life

Ran Xiao, Beth A. Smith

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Background and Objectives: Electroencephalography (EEG) power represents amount of activity in certain frequency bands of the signal. Our goal in the present study was to complement previous studies demonstrating a relationship between infant mu rhythm development and motor skills, while expanding upon them by assessing a novel group: younger infants at risk for developmental delay (AR) across the time period during which they learn to reach with their arms.

Study Design: Observational study of prognosis (natural history).

Study Participants & Setting: We collected data from a volunteer sample of 11 infants broadly AR (6 high risk preterm, 4 low risk preterm, 1 high risk full term). Participants were between 40 and 225 days of age (adjusted for prematurity), recruited from Los Angeles area healthcare providers. Infants were measured 3-5 times each, with 1 month between measurements, for a total of 43 measurements.

Materials/Methods: EEG data were collected at 512 Hz using a Biosemi system with 32-electrode caps. Infants sat on a caregiver's lap and looked at a spinning light toy (minimum = 40 s, maximum = 2 m). Power spectral density (PSD) was estimated to obtain relative powers between 0 and 30 Hz. For each frequency bin within this range and each electrode, relative power was computed by dividing PSD by the sum PSD from all bins. All procedures and analyses are described in our publication (1).

Results: Figure 1 presents the spectral profiles in 2-10 Hz of infant EEG, by age, for the average key representative electrodes from left, medial and right motor cortices (C3, Cz and C4). The development of a peak at 6 Hz as infants get older can be appreciated.

Conclusions/Significance

Changes can be observed within 2-3 Hz, 3-5 Hz and 6-9 Hz bands, however the former two do not present conclusive changing patterns along maturation, with monthly spectral profiles interweaving among earlier and later months of age. On the contrary, alpha activities from motor cortices present a quite consistent increasing pattern along maturation. In 21 infants with typical development, the peak develops at 7 Hz (1) as opposed to 6 Hz observed here. The results here are from a small sample of heterogeneous infants AR and need to be interpreted with caution; whether this observed difference between groups is important remains unknown. In future work, we plan to relate changes in spectral profiles to arm reaching skill and developmental outcomes for infants AR.

1. Xiao et. al, PLOS One, in press. Electroencephalography power and coherence changes with age and motor skill development across the first half year of life.

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97. Lack of generalization between explicit and implicit visuomotor learning

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Abstract:

Visuomotor adaptation has been previously thought to occur implicitly, although recent findings suggest that it involves both explicit and implicit processes. Here, we investigated generalization between an explicit learning condition, in which subjects reached toward imaginary targets under a veridical visuomotor condition, and an implicit condition, in which subjects reached toward visual targets under a novel visuomotor rotation condition. In experiment 1, a group of healthy young adults experienced the explicit, then the implicit condition; another group experienced the implicit, then the explicit condition. Results showed initial explicit learning did not facilitate subsequent implicit learning, or vice versa. In experiment 2, the generalization was further investigated by testing additional subject groups who first experienced the explicit condition, then an implicit condition with an instruction, an implicit condition with an opposing visuomotor rotation, or a reaching condition without visual feedback. When provided with an instruction, subjects adapted to the rotation faster, although the effect of initial explicit learning was minimal. When the opposing rotation was provided, generalization between the explicit and implicit conditions was still minimal. Finally, implicit learning resulted in aftereffects, whereas explicit learning did not. These findings collectively suggest that visuomotor adaptation mainly involves implicit, but not explicit, components.

98. Sensory assessment of stroke patients

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Abstract:

Stroke is the leading cause of long-term physical disability in the United States. Physical rehabilitation following a stroke is crucial for recovery, improving patient independence, and reducing cost for outpatient services. However, traditional and current approaches have ignored intrinsic asymmetries and rarely differentiate the specific sensory and/or motor needs after stroke. For this reason, the goal of this pilot study was to investigate the alteration of sensory information from each limb/hemisphere system in mildly to moderately affected stroke patients. The sensory systems were tested by passive proprioceptive perception of upper limb position and movement. Position sense was tested with eyes closed while participants matched a reference position imposed by a robotic arm in two different conditions: ipsilateral remembered and contralateral concurrent. Movement sense was tested with eyes closed while participants reproduced with the opposite arm the perceived movement elicited by a vibration applied to the distal tendons of the triceps muscle of the reference arm. The preliminary results were obtained from two patients whose left hemisphere was affected by a mild and moderate stroke, respectively. The results indicate a significant alteration of position and movement sense asymmetry between right and left limb systems. They vary largely between the patients; however sensory alterations are pronounced in both. A lack of consistency was observed for the patient affected by a moderate stroke and a motor deficit is likely for that patient. It is worth noting that "asymmetry exacerbation", which does not mean greater errors, is to be considered when comparing to intrinsic asymmetries in healthy controls.

99. Sense of effort: right and left hand sensitivity to proprioceptive feedback.

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Abstract:

The contribution of sensory feedback to the sense of effort is still debated. A recent study indicated that in a contralateral force-matching task the influence of reference hand vibration was significant for left hand matching of the right hand reference force. However, this effect was negligible when matching in the reverse condition. In addition, a difference in muscle proprioceptive sensitivity between males and females has been observed in another study. Hence, the aim of this study was to investigate the sensitivity of the left and right hand sensory systems to vibration induced changes in force control and correlated changes in electromyographic (EMG) activity. Twenty strongly right handed young adults (10 males and 10 females), free from any neurological disorders, participated in the study. Participants were asked to grasp fixed horizontal cylinders instrumented with strain gauge transducers and exert a reference force of 20% maximum voluntary contraction (MVC) with the right or left hand. It was required to establish the reference force level and then maintain that force for about 12 seconds with or without visual feedback of the force level. Five seconds after stabilization of the exertion an 80 Hz vibration was applied to the distal tendons of the finger flexor muscles. EMG activity was recorded from each hand finger flexor muscles and normalized to each hand 100% MVC. Changes in force and EMG activity were quantified for each hand. The results show that the vibration-induced increase in EMG activity is significantly greater for the left than the right hand. This increase is significantly greater for females than males. These results suggest that the gain of the proprioceptive system is greater for the left than right hand, which confirms previous results concerning position sense.

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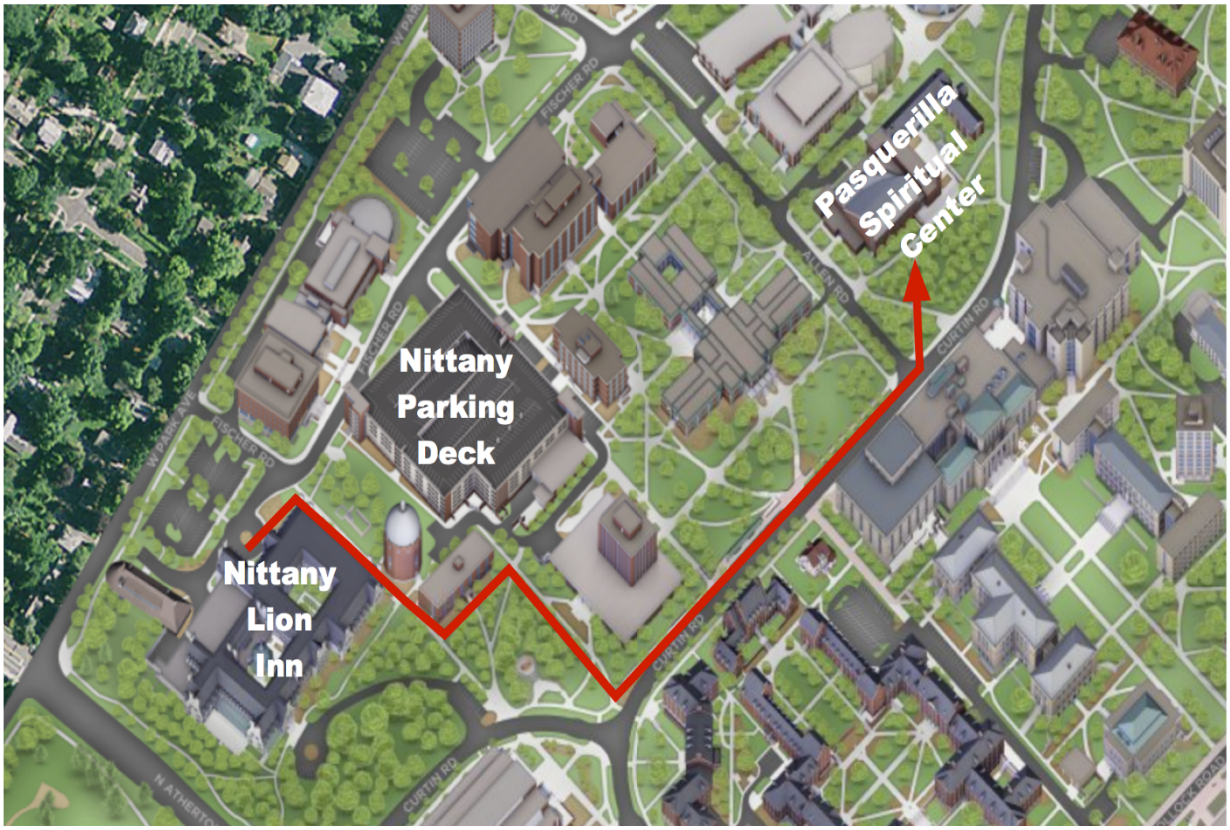

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