2020

Motor Control and Learning

JO VAN VAERENBERGH

Introduction

Motor control *is a complex problem and considers the organization and production of movement within a particular space. Motor control has been approached from a wide range of disciplines, including psychology, cognitive science, biomechanics and neuroscience. The control of human movement has been described in many different ways with many different models of Motor Control put forward. Motor Control Theories include production of reflexive, automatic, adaptive, and voluntary movements and the performance of efficient, coordinated, goal-directed movement patterns which involve multiple body systems (input, output, and central processing) and multiple levels within the nervous system. As a therapist it is these key areas that we need to be aware of when planning our interventions. As therapists we can change the environment, or the task in such a way as to enable our patients to achieve their goals.*

Motor learning *is when complex processes in the brain occur in response to practice or experience, resulting in changes in the central nervous system that allow for production of a better control. It often involves improving the smoothness and accuracy of movements, but it is also important for calibrating simple movements like reflexes, as parameters of the body and environment change over time. Motor learning research often considers variables that contribute to motor programming, sensitivity of error-detection processes, and strength of movement schemas.*

Learning Methods

The chosen methods of content presentation are listed after each content section. The abbreviation are explained here below:

LE= Lecture

DI= Discussion

PR= Practice

DE= Demonstration

TE= Testing

AS= Assessment

RE=References to state of the art scientific literature

Content

This course will present content relating to motor control and neuroscience theories and principles, and will examine the role of the neuromuscular system in both the sensory and motor aspects of motor control. The purpose is to provide you with evidence to understand how motor skills are performed and learnt in relation to everyday activities with a particular focus on disease populations such as brain trauma, Parkinson's and other movement disorders.. The course content will develop understanding of principles for learning and re-learning of motor tasks and skills.

***General concepts**: Importance of numerical models in the scientific approach of human motor control, introduction to the understanding of non-linearity in human dynamics and short introduction to adaptive control theory. (LE-DI-RE)*

Course time: 4 hours

Internal model and adaptive control are empirical and mathematical paradigms that have evolved separately to describe learning control processes in brain systems and engineering systems, respectively. From a behavioral perspective, the terms “learning” and “adaptation” are sometimes taken to connote, respectively, an active or voluntary construction of new actions as opposed to a passive or involuntary adjustment to a novel environment. Such semantic distinction becomes less and less relevant in terms of rehabilitation….

[Objective: the learner can make a global difference between low level and high level control, such as for example resetting α and γ loops by means of peripheral electrical stimulation in a spastic patient versus updating the internal model during object manipulation in a patient with sensory loss.]

***Numerical models of motor systems** : Neural network models of control of locomotion, rhythm generation in central pattern generators, reflexes, force fields, sensory-motor coordination, and balance control. (LE- TE- DE- PR- DI- AS- RE)*

Course time: 4 hours

Rhythmic locomotor behavior requires exact timing of muscle activation within the locomotor cycle. In rapidly oscillating motor systems, conventional control strategies may be affected by neural delays, making these strategies inappropriate for precise timing control. Some types of control thus require sensory processing within the peripheral nervous system, circumventing the central brain other types needs the ability to predict the future course of actions and the results of ongoing behaviors, and in general to plan actions well in advance. These models are called 'internal models', meaning that they are the internal rehearsal (or simulation) of the world enacted by the brain….

[Objective: to detect in a stroke patient central timers when it comes about gait optimization, understand the difference of studying a rehabilitation problem in the time of frequency domain]

Numerical models of the musculo-skeletal system and related sensors*: muscle models, proprioception, biomechanical models of locomotion, Spring-Loaded Inverted Pendulum (SLIP) model, gait classifications (LE- TE- DE- PR- DI- AS- RE)*

Course time: 4 hours

Sensory input from a variety of sources is involved in the control of movement. The receptors include muscle spindles, Golgi tendon organs, joint receptors, skin receptors, and receptors that influence circulatory and respiratory adjustments during exercise. The properties of the sensory receptors that are the most closely involved in the sensory control of movement will be reviewed. We will then consider how sensory input from these receptors interacts with neural networks in the central nervous system (CNS) to generate purposeful movement. The human upper extremity contains about 4000 muscle spindles, 2500 Golgi tendon organs, and a few hundred joint receptors. The human hand alone has around 17,000 myelinated cutaneous afferents. The role of these sensors for understanding spasticity, treatment and rehabilitation is therefore crucial.

[Objective: to understand the importance of the peripheral sensors in relation to position and force control, applying this knowledge to the understanding of prehension and loss of dexterity in stroke patients, especially when it comes about fast movements and/or object manipulation and writing]

Numerical models of arm movements*: invariants of human arm movements, different hypotheses about human motor control: inverse models and equilibrium point hypothesis. (LE, TE, DE, PR, DI, AS)*

Course time: 4 hours

The performance of adaptive control is generally assessed according to certain rigorous criteria such as stability, convergence and robustness. Stability means that when a system is sufficiently close to equilibrium, the system states can be kept arbitrarily close to the equilibrium point under perturbation and return to the equilibrium point when the perturbation is removed. Convergence means that given a bounded input, the output will be bounded and tends to a steady state over time. Besides output convergence, convergence of the parameter estimates for the plant (i.e., the process to be controlled) and controller to their true values is also of major concern in adaptive control and system identification problems. Finally, an otherwise stable controller may become unstable in the presence of small disturbances or unmodeled dynamics. Robustness describes the amount of such uncertainty the system can tolerate before controller performance is significantly compromised. Such performance measures are fundamental to the adaptive control design but are not sufficiently included in the study of human sensorimotor systems. Incorporation of such performance assessment is crucial in that it may aid in hypothesis testing and follow up of recovery processes, i.e., a proposed model paradigm may be rejected if it does not demonstrate the stability, convergence and robustness characteristics expected during training.

[Objective: understanding stability in terms of joint stiffness and muscle synergies and use it for building graded exercises in stroke patients, understanding redundancy and ADL tasks in terms of speed/accuracy trade off and cost/ energic efficiency]

***Numerical models of the vestibular and visual system** : The vestibular system. Visual processing in the retina, collision detection. (LE- TE- DI- RE)*

Course time: 4 hours

The vestibular system is the apparatus that detects information about spatial position and movement of the head and of the body. This information is a fundamental input to control the posture, the upright position and to coordinate eye and head movement. The vestibular is quite a complex system and not all of the mechanical-nervous transduction mechanisms are completely known; this is also due to the impossibility of directly measuring human nervous signals.

Humans constantly interact with a dynamic environment. These interactions can include an observer moving toward a stationary object, an object moving toward a stationary observer, or a combination of both thereof. In this section sources of information, which are used to mediate these types of interactions are discussed. Given that the time required for performing an action is biologically constrained and often fixed (i.e., resulting from a sequence of muscle movements), humans use predictive timing information specified by visual information to guide their actions. One potential source of information often focused on is time to collision and is defined as the time remaining before contact between the observer and object.

[Objective: understanding visuospatial problems in stroke patients and use the knowledge to manipulate where and what pathways in the brain (ventral and dorsal streams), understanding joint position calculations in a body, eye and allo-entered frame during catching of objects]

***Use of Robotics in Neurorehabilitation**: short overview of current developments, analysis of how body-machine interfacing can be a source of motor learning. (DI- RE)*

Course time: 2.5 hours

There is increasing interest in using robotic devices to provide rehabilitation therapy following stroke. Robotic guidance is generally used in motor training to reduce performance errors while practicing. However, up to date, the functional gains obtained after robotic rehabilitation are limited. A possible explanation for this limited benefit is the inability of the controllers to adapt to the subjects' special needs. Research on motor learning has emphasized that movement errors are fundamental signals that drive motor adaptation. Thereby, robotic algorithms that augment errors rather than decrease them have a great potential to provoke better motor learning and neurorehabilitation outcomes, especially in initially more skilled subjects. Although there is an initial body of work that compared the effectiveness of robotic strategies that amplify or reduce movement errors on motor learning, results are still inconclusive. A possible rationale is that studies have searched for the strategy that enhances learning, independently of the subjects' individual needs and the characteristics of the task to be learned. Some theories have suggested that optimal learning is achieved when the difficulty of the task is appropriate for the individual subject's level of expertise. Additionally, the specific characteristics of the task to be learned might play an important role on motor learning outcomes. Adaptability becomes a main issue in standardization of therapy. A highly adaptable approach and most likely a more effective compromise classical statistics asking for a ‘controlled and standardized design’.

[Objective: understand the control strategies of the in-house robots and compare them with manual therapeutic interventions, describe the optimal control process expected for a robot aided intervention]

Learning Outcomes

By the end of the course, the participants must be able to:

1. *Argue about the validity of a model in relation to the observed pathology*
2. *Formulate models of motor control in relation to a proposed therapy*
3. *Hypothesize mechanisms of motor control as a basis for concept change*
4. *Design exercises in relation to models of motor control presented within the frame of a particular pathology*
5. *Propose a method of evaluation in relation to the disease fitted model including milestones of recovery*