Application of neuromuscular fitness, Gymnastics

Investigators in neuromuscular biomechanics bring together computational physics, neuroscience, and robotics to analyze muscle form and function, study human movement, design medical technologies, and guide surgery. This driving biological problem seeks fundamental understanding of the mechanisms involved in the production of movement, and is motivated by opportunities to improve treatments for individuals with cerebral palsy, stroke, osteoarthritis, and Parkinson's disease. Prof. Scott Delp, a pioneer in the development of methods for modeling motor systems is the lead investigator of this multi-institutional effort.

Now a day's software for creating musculoskeletal models and for performing and analyzing dynamic simulations of human and animal movement create a lot of attention.

Creating a new paradigm for muscle modeling that represents muscles as three-dimensional volumes, incorporates the complex three-dimensional arrangements of muscle fibers, specifies nonlinear constitutive properties of muscle, and accounts for the mechanics of muscle-bone and muscle-muscle contact. To provide general multibody dynamics capability, this can be used for internal coordinate modeling of molecules, or for coarse-grained models based on larger chunks. It is also useful for large-scale mechanical models, such as neuromuscular models of human gait.

Single software tool for doing a variety of operations on medical images including registration, segmentation, and 3D model building, 3D Slicer software and was customized for the modeling pipeline used in neuromuscular biomechanics.

Just as interactive graphics have enhanced engineering analysis and design, the graphics-based musculoskeletal models are effective tools for visualizing human movement, analyzing the functional capacity of muscles, and designing improved surgical procedures and computer models helps in many ways to record different musculoskeletal structures.

Neuromuscular Exercise Program

Introduction

It's an evidence-based supervised neuromuscular exercise targeting Hip and Knee Osteoarthritis. Neuromuscular control is defined as the unconscious trained response of a muscle to a signal regarding dynamic joint stability. The movements of the lower extremity, including the knee joint, are controlled through this system, which needs to provide the correct messaging for purposeful movement. Neuromuscular training programs should address several aspects of sensorimotor function and functional stabilization to improve objective function and alleviate symptoms. The neuromuscular training method that is described is based on biomechanical and neuromuscular principles and aims to improve sensorimotor control and achieve compensatory functional stability. Unlike conventional strength training, neuromuscular exercise addresses the quality of movement and emphasizes joint control in all three biomechanical/movement planes. Neuromuscular exercise has effects on functional performance, biomechanics, and muscle activation patterns of the surrounding joint musculature. Simply restoring mechanical restraints is not enough for the functional recovery of a joint because the coordinated neuromuscular controlling mechanism required during daily living and sport-specific activities would be neglected. Rehabilitation programs cannot alter mechanical joint instability but may affect neuromuscular control and dynamic joint stability. A lag in the neuromuscular reaction time can result in dynamic joint instability with recurrent episodes of joint subluxation and deterioration. Therefore, both mechanical stability and neuromuscular control are probably important for long-term functional outcome, and both aspects must be considered in the design of a neuromuscular rehabilitation program. Sensorimotor control or neuromuscular control is the ability to produce controlled movement through coordinated muscle activity. Functional stability or dynamic stability is the ability of the joint to remain stable during physical activity.

Mechanisms for Sensorimotor Deficiency

Impairments are present at different levels of the sensorimotor system, from sensory input through integration and processing of information in the central nervous system to motor output to perform voluntary movements and maintain postural control. It has been suggested that sensorimotor dysfunction also may play a role in the development and progression of degenerative joint disease. Neural inhibition caused by factors such as pain, swelling, inflammation, joint laxity, and damage to sensory receptors in the joint prevents the muscle to be activated fully likely through altered excitability of spinal and supraspinal pathways. Sensorimotor deficiencies also were found in the noninjured leg compared with controls possibly because of factors such as physical inactivity after the injury, inherently poor function, and/or disturbed sensory feedback from the injured joint with an inhibitory effect of muscle activation also on the noninjured side.

Neuromuscular adaptation to training

The hallmark adaptation to resistance training increases muscles strength and muscle size (hyper trophy).

Adaptations to High-Resistance Strength Training

Progressive resistance training refers to any type of training that aims to increase muscle strength, power and size through muscular contraction. This mode of exercise relies on the overload principle where strength is improved and muscle growth stimulated by exercising/working a muscle close to its maximal force generating capacity. A typical programme might involve 6-8 repetitions of lifting and lowering a weight, with these sets being repeated 3-4 times and using loads that which are equal to approximately 70-80% of maximum weight that can be lifted once.

Neural Adaptations

- Increased central drive (from the higher centers of the brain) after resistance training is partly responsible for the increase in strength
- Increased Motor Unit (MU) synchronization (several MU's firing at similar times)
- Decrease in the force threshold at which Motor Units are recruited
- Increased Motor Unit firing rate
- Decrease in the level of co-activation of antagonist muscles after training

Muscular Adaptations

Skeletal muscle will adapt to mechanical overload by increasing in muscle size. With resistance training various signalling mechanisms are activated and these initiate the creation of new proteins and the enlargement of muscle fibre and muscle cell size leading to hypertrophy with little evidence showing an increase in the number of muscle fibres (hyperplasia) taking place. Various adaptations include:

- Increase in the cross sectional area of the muscle
- Changes in muscle architecture
    - Ultrasound studies have shown changes in the angle of fiber pennation (the angle at which fibres are aligned in regards to their insertion to the aponeuroses of the muscle). This will affect force output by determining the physiological cross sectional area (where the cross-section area is determined perpendicular to the line of pull of the muscle fibres).
- Hypertrophy of fibre types at cellular level, especially in Type II fibres:
    - Research shows a decrease in the number of Type IIx fibres, together with an increase in Type IIa fibres

- Fast twitch muscle fibres are inherently stronger (greater force per unit area) and have a high speed of shortening, therefore "a given enlargement of a fast twitch fibre should have a proportionately greater effect on strength and power than the same growth of a slow twitch fibre."

Muscle Protein Synthesis

It is well-known that muscle is sensitive to training loads. The muscular system is a dynamic system with proteins being synthesised and degraded. For muscle growth the balance between protein synthesis and degrading needs to be changed. This can occur by either increasing the synthesis rate or decreasing the rate of degrading or a combination of both.

Important findings to know about human muscle protein turnover:

- Muscle protein synthesis is ~ 0.04% per hour in the fasted state
- Exercise and feeding stimulate muscle myofibrillar protein synthesis
- Following resistance training muscle protein synthesis increases 2x - 5x post exercise
- Increases in protein synthesis occur 1 - 2 hours post exercise, but in the fed state it can remain increased for 48 - 72 hours
- An elevated protein breakdown accompanies this increase in protein synthesis post exercise
- In a fed state, protein synthesis is greater than protein breakdown, resulting in a net gain of protein
- The accumulated effect of this process over multiple exercise bouts leads to a net gain in protein and therefore muscle growth.

The above-mentioned findings clearly shows that adaptations to muscle are dependent on nutrition availability. The protein synthesis and breakdown response post exercise can be adjusted by altering the availability of certain nutrients. Both, resistance training and amino acid ingestion increases protein synthesis. When these two factors are combined it has an even bigger effect. The consumption of protein post exercise does the following:

- Promotes protein synthesis
- Suppresses protein breakdown

With the suppression of protein breakdown post exercise in the fed state, there is also an increase in insulin levels which further aids this suppression of protein breakdown. It is therefore important to maintain adequate nutrition to maximise the benefits of resistance training.

Satellite Cells

Satellite cells are specialised muscle stem cells located in a niche between the basal lamina and the sarcolemma of a muscle fibre. They aid in the growth and repair of all skeletal muscle. These cells are activated by muscle damage and/or sufficient exercise. Once these cells are activated they proliferate differentiate and fuse to an existing myofiber, and in this way forming new contractile proteins and repair damage. Resistance training results in an increase in the number of satellite cells within four days of training. With continued resistance training over an extended period of time satellite cell numbers can increase by ~30% and can furthermore remain elevated even if training is stopped.

Another important role of satellite cells is the donation of their nuclei to act as post-mitotic nuclei in the growing muscle fibre.

Adaptations to Endurance Training

Endurance training is focused on increasing muscle fatigue resistance for exercise of longer duration. Fatigue is defined as: "a loss in the capacity for developing force and/or velocity of a muscle, resulting from muscular activity under load and which is reversible by rest." Performance in endurance activities is dependent on the body's ability to produce sufficient ATP through aerobic respiration. This process requires the neuromuscular, cardiovascular and respiratory systems to interact. Essentially, endurance training and activity enhances the oxidative capacity and metabolic efficiency of skeletal muscle. The adaptations that it achieves this through are: oxygen utilisation (mitochondrial adaptations), oxygen delivery (angiogenesis) and local substrate availability.

Neuromuscular training programs are found effective in improving function and reducing symptoms in people with knee issues. Neuromuscular exercises in lower extremities would involve multiple joints and muscle groups performed in functional weight-bearing positions.

Emphasis is on the quality and efficiency of movement, as well as the alignment of the trunk and lower limb joints. To improve sensorimotor control, exercises are performed mainly in closed kinetic chains in different positions (e.g., lying, sitting, standing) with the intention to obtain low, evenly distributed articular surface pressure by muscular coactivation. Several aspects of sensorimotor function, such as strength, coordination, balance, and proprioception, are included in the Neuromuscular exercises, but focus can be, for example, balance in one exercise and strength in another. The goal is to obtain equilibrium of loaded segments in static and dynamic situations and acquire postural control in situations resembling conditions of daily life and more demanding activities. Emphasis is put on the efficiency and quality of movements of each exercise. The training is individualized because symptoms and functional limitations are heterogeneous in people with an injury or disease. The level of training and progression is guided by the patient's sensorimotor function, taking into account various factors related to the individual and the injury/disease.

Adaptation to Exercise: The Overload Principle

The overload principle is responsible for the improvement in exercise as well as the adaptation to exercise. The muscular system can be mechanically or metabolically overloaded. These mechanisms result in specific and different adaptations that enhances performance. The magnitude of these adaptations is dependent on:

- The type of exercise
- The intensity of exercise
- The frequency of exercise
- The duration of exercise

There is also emerging evidence for other factors also playing a role such as:

- The initial level of fitness
- Genetic influences which determine the body's responsiveness (responders and non-responders) to given training interventions

The mode of exercise (e.g. strength training or endurance training) influences the type and magnitude of adaptation in the neuromuscular system. For example if endurance training (high repetition, low load contractions) is undertaken the muscular system will undergo specific changes that targets aerobic metabolism and improved fatigue resistance. Strength training (low repetitions with high load contractions), in contrast, will cause muscle adaptations such as increased myofibrillar protein synthesis. As a result muscle size, strength and power may increase and improve. Another principle to consider is specificity. The type of exercise performed is important to consider within the context of training. The principle of specificity states that only the system or body part repeatedly stressed will adapt to chronic overload. Thus, "specific exercise elicits specific adaptations creating specific training effects."

Mitochondrial Adaptations (Oxygen Utilisation)

Mitochondria are the "powerhouse" of the cell. These organelles generate the majority of the cell's supply of ATP through aerobic respiration. Endurance training can increase the volume and number of mitochondria and the magnitude of these changes are dependent on the frequency and intensity of training. With the increased number and size of mitochondria, the proportion of pyruvate formed during glycolysis passing into the mitochondria for oxidative phosphorylation is increased with less used for the production of lactate and its by-products. As a result the exercise intensity, which can be sustained through relying on aerobic metabolism, is higher.

Angiogenesis (Oxygen Delivery)

The network of capillaries adjacent to the muscle fibres is responsibly for the diffusive exchange of gasses, substrates and metabolites between the circulation and the working muscle fibres. Endurance training results in the growth of new capillaries (process of angiogenesis), with an increase of ~20% being present after 8 weeks of training in both Type I and Type II fibres

Substrate Utilisation

During submaximal exercise the main fuel sources are carbohydrates (mainly muscle glycogen) and fats (local and circulating fatty acids). Endurance training leads to a key adaptation in substrate utilisation:

- for a given level of submaximal exercise the contribution of fatty acid oxidation to the total energy requirement increases with a marked increase in the muscle's ability to utilise intramuscular triglycerides as the primary fuel source.
- Training results in more glycogen being stored in muscle fibres, in form of granules, this leads to a greater number of intramuscular lipid droplets being in contact with the mitochondria
- Endurance athletes rely on on improved fatty acid oxidation as it conserves muscle glycogen stores (these are more needed during exercise of high intensity)

Neural Adaptations

With endurance training the following adaptations occur in the neural system:

- Motor unit discharge rate decreases
- Slower rate of decline in Motor unit conduction velocity during sustained contractions is found after endurance training
- Decrease in Motor unit recruitment thresholds

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