Mother Nature is a Cheapskate: Biomechanical Energy Saving Devices Exposed

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A basic principle of normal musculoskeletal function directed by the central nervous system is an economy of energy usage. This is exemplified in many ways and illustrated by a long series of electrokinesiologic studies I have carried out and reported with many students and associates over a 40 year span. A few mechanisms will be described, but they are fully discussed in my book, Muscles Alive (Basmajian and DeLuca, 5th edition, 1985).

COORDINATION, ANTAGONISTS AND SYNERGY

While it is a truism that the brain orders movements of joints and not contraction of muscles, some actions are produced by onlyone or two muscles. For example, simple pronation of the forearm is usually produced by one muscle alone -pronator quadratus- unless added resistance is offered to the movement; then, more muscles are recruited. In elbow flexion brachialis alone often suffices. Complex movements (such as rotation of the scapula on the chest wall during elevation of the limb) always call upon groups of cooperating muscles.

Many believe that during the movement of a joint in one direction, the muscles that move it in the opposite direction show some sort of antagonism. However, Sherrington's "reciprocal inhibition" is the rule with skilled movements: the so-called antagonist relaxes completely except during a whip-like motion of a hinge joint. The brief terminal activity in antagonists serves a protective function to avoid damage while such a force is in the prime mover could produce. Generally it is now agreed that voluntary slow movements in normal man do not cause stretch-reflex cocontraction of the antagonists; rather, such contractions occur only with rapid movements.

There is a pattern of responses in which low unsustained activity occurs in antagonists at low speeds of voluntary flexion and extension of the elbow; at middle speeds there are successive activities in the agonist and antagonist, including common electrical silence; at high speed of flexion and extension there is partial overlapping phasic activities in agonist and antagonist.

In effect, cocontraction of antagonists occurs to a greater or lesser degree in some movements, in some people, at some ages and under some circumstances. With increasing age and training at slower speeds, it tends to reduce to nil. When it occurs, it sometimes is due to reflexes and sometimes appears to be an extravagant overflow. Because nervous coordination is so fine, there is no need for muscles to act consistently in antagonism to others.

CONTROL OF MOVEMENT

Skilled movements are performed with an economy of muscular actions dependent upon impulses being sent to only one or two muscles or even a localized area of one muscle. What the brain has "learned" is patterning of these actions by means of a progressive inhibition of the inefficient mass responses that were natural to the child. Some movements are extremely economical in the well-trained person. Muscles have several (sometimes many) component parts which are recruited in different functions at different times. Local activity is patterned by progressive inhibition of motoneurons until an acceptable performance is achieved. Our studies of elbow flexion and thenar muscles that show the interplay of motor unit functions dedicated to specific postures and movements clearly indicate that the positioning of limbs is predetermined by sets of motor units which are permitted to act for that position. The same appears to be true for well-learned movements. The learned patterns are called "specificity" by physical educators. The mosaic of spinal motoneurons is dedicated to the learned response of a specific posture or movement of a joint through space. The ultimately superior performance of a skilled movement depends on the reproducibility of the idea., an economically spare mosaic of motoneuronal activity.

Given visual and auditory cues through electronic amplification and feedback, subjects can be quickly trained to consciously activate single motoneurons with great precision. But conscious activation of single motoneurons in the single-motor-unit training paradigm depends on the same principles as the learning of any other novel tasks, that is, progressive (and sometimes rapid) inhibition of the motoneuronal activitv that adds no useful function in producing a desired motor response.

Training, whether it is the unconscious process of the child learning simple social motor responses or the preparation for a specific skilled act (such as those of musician or athlete), is a progressive inhibition of many muscles that flood into play when one first attempts to produce the required response. The athlete's continued drill to perfect a skilled movement exhibits a large element of progressively more successful repression of undesired contractions. The young animal has enormous amounts of overactivity and reactive contractions in muscles that are serving no directed purpose in producing the desired movement or posture. As children mature this overactivity disappears and is absent in normal adults. It reappears in adults under psychological stress, but people can be trained to inhibit it to varying degrees. In patients with diseases and injuries of the central nervous system, the normal inhibition pattern is lacking; then mass responses from local interoceptive and exteroceptive bombardments of the motoneurons result in an exaggerated mass response described as spasticity.

MUSCLE MECHANICS

Two-joint muscles

A two-joint muscle is one that not only crosses two joints but is also known to act on both, e.g. rectus femoris, the hamstrings, gracilis and sartorius, biceps brachii and the long head of triceps.

The effect of contraction of two-joint muscles is never limited to one joints; whenever a two-joint muscle participates in a monarticular motion, its role shifts in close coordination with the other muscles. We showed that in biarticular concurrent motion the activity of the rectus femoris and the medial hamstrings is inhibited when they are antagonists, especially when the motion of the knee is concerned.

Muscle sparing

Ligaments play a much greater part in supporting loads than is generally thought. In brief, in many normal postures even heavy transarticular loading does not recruit muscular activity. Included are the shoulder, elbow and foot in the normal posture and during suspension by the hands. Contrary to expectation, the vertically running muscles are not active to prevent the distraction one might expect. During suspensory behaviour by apes, we found that muscles in the upper limb that might be expected to act against the force of gravity remained silent in simple hanging.

There are special inert mechanisms for prevention dislocation. For example, in the shoulder joint we have proved that coracohumeral ligament (a great thickening in the superior capsule of the joint) provides the locking mechanism for the shoulder joint in the normal hanging position of the arm.

POSTURE

The idealized normal erect posture requires muscular activity to be called upon to approximate this posture, or, if the body is pulled out the line of gravity, to bring it back into line.

In man, the column of bones that carries the weight to the ground constitutes a series of links. Ideally, these links should be so stacked that the line of gravity passes directly through the centre of each joint between them. But even in man this ideal is only closely approached and never completely reached - and then only momentarily. However, muscular activity of antigravity muscles in standing is slight or moderate. Sometimes it is only intermittent. On the other hand, the posture of quadrupeds, which is maintained by muscles acting on a series of flexed joints is highly dependent on continuous support by active muscular contraction. Of course the same is true for the human being in any but the fully erect standing posture.

Shifting from foot to foot in ordinary standing is a relief mechanism for relief to the inert structures is perhaps even more significant.