Reflexes: principles and properties

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Abstract

The body responds to changing circumstances and environmental threats both consciously and subconsciously. The cognitive response to a physical threat normally involves movement mediated by skeletal muscle. There are a number of control mechanisms 'hardwired' into the nervous system that enable muscle systems to respond in an integrated fashion without involving a conscious decision, although the subject is usually conscious of what has happened. These include the stretch reflex, the withdrawal reflex and the crossed extensor reflexes. Muscle spindles, Golgi tendon organs and cutaneous nociceptors provide the sensory input to these reflexes, and muscle spindles also play a role in the control of voluntary movement. The autonomic nervous system controls the internal environment in response to environmental change. It consists of the parasympathetic division, which controls basal and vegetative mechanisms, and the sympathetic nervous system, which controls visceral adaptive responses to any sort of environmental change or threat.

Keywords Fight-or-flight; neurotransmitters; sympathetic and parasympathetic nervous system; synapses; withdrawal and crossed extensor reflexes

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Learning objectives

After reading this article you should:

- understand the basic components of a spinal reflex arc (somatic nervous system) and to illustrate these by reference to the stretch reflex, the crossed extensor reflex and the withdrawal reflex
- know details of the way in which the stretch reflex (originating from the muscle spindles) maintains posture and can also be reset to allow voluntary movement. The importance of the dynamic and static sensitivities of muscle spindles and of gamma efferents. The role of the inverse stretch reflex (originating in the Golgi tendon organs) in preventing damage due to excessive tension in the muscles
- appreciate the roles of the withdrawal and crossed extensor reflexes, and interactions between them as stimulus strength increases
- understand differences (receptors, effector organs and reflex pathway) and similarities (components of the reflex arc and independent of cognition) between somatic and autonomic reflexes
- be able to give an outline of the variables controlled by the autonomic reflexes, to show knowledge of the parasympathetic and sympathetic pathways involved, and to have an appreciation of the general differences in the roles played by the parasympathetic and sympathetic components of the autonomic nervous system
- be able to outline the role of autonomic reflexes in controlling pupils of the eye, motility of the gastrointestinal tract and secretions from it, and the cardiovascular and respiratory systems, and the integration of these in the 'fight-or-flight' response to potential injury

The concept of homeostasis — maintaining the constancy of the internal environment — is fundamental to physiology. For this constancy to be achieved, a sensor (to measure the variable being controlled), an effector (to change this variable) and some linking pathway are required. Homeostasis results when these components act together, forming negative feedback loops. Similar components are needed when adaptation to change is required — escaping from a noxious stimulus or predator, for example — although they will be 'wired together' differently to implement change rather than to maintain a steady state. The activities of the various 'excitable tissues' — sense organs, neurones and muscles — are integrated so that various controlled processes can ensue. Many of these processes do not require cognition ('thought') but are automatic. They occur also on two levels: those involving the somatic nervous system, integrated at the level of the spinal cord but of which the subject is generally aware (walking, maintenance of posture); and those concerning the autonomic nervous system (digestion of food, cardiac and metabolic responses to a stressor), of which the subject is not normally aware. These latter reflexes are integrated at the level of the midbrain and medulla.

Somatic reflexes

The stretch reflex is the basis of posture and is responsible for maintaining a set length for the muscles that support the weight of the body, so preventing us from falling over as a result of the influence of gravity. This reflex can be observed when tapping the tendon of a muscle; the rapid stretch produced by the tap results in a reflex contraction of the muscle, seen most commonly with the patellar tendon of the quadriceps femoris or the triceps tendon above the elbow. The sensor organ in the skeletal muscles is the muscle spindle, which detects stretching of the muscle; the effector organ is the voluntary striated muscle supplied by α-motor neurones from the ventral root of the spinal cord. These two components combine in a negative feedback loop that maintains muscle length and posture.

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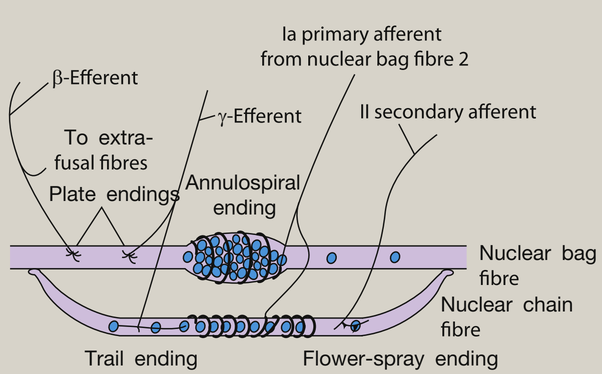
The muscle spindle is a complex structure consisting of up to ten muscle fibres enclosed in a connective tissue capsule. These are termed 'intrafusal' fibres, to distinguish them from the 'extrafusal' fibres that make up the bulk of the muscle, and which produce the contractile force when the muscle shortens. They are connected to the tendons at each end of the muscle or to the sides of the extrafusal fibres.

There are two types of intrafusal fibre — nuclear bag and nuclear chain fibres (Figure 1). A muscle spindle consists of about two nuclear bag fibres and four or more nuclear chain fibres. Nuclear bag fibres have contractile ends and a non-contractile central dilated area containing several nuclei. The nuclear chain fibres are smaller and their nuclei are laid out along the length of the fibre. As implied above, the muscle spindles are stretch receptors. They give rise to two types of large-diameter, afferent (sensory) fibre: group Ia afferents arise from annulospiral endings around the central section of both types of intrafusal fibre; group II afferents arise from 'flower-spray' endings around the ends of the nuclear chain fibres. Both types of afferent fibre pass into the dorsal root of the spinal cord, the cell bodies lying in the dorsal root ganglion, and form monosynaptic connections with the α-motor neurones supplying the extrafusal fibres of the same muscle. The fact that both the afferent and efferent fibres are of large diameter, coupled with the presence of only one synapse in the pathway, means that the stimulus response delay time is minimal, about 20 milliseconds in the case of a simple 'knee jerk'.

The spindles are arranged in parallel with the extrafusal fibres of the muscle and monitor its length. If the muscle is stretched, the spindles produce more afferent impulses and these cause the muscle to contract (as with a knee jerk), so opposing the original stretch. By contrast, if the muscle length decreases then the spindle is unloaded and its rate of firing is reduced; the resultant reduced rate of firing of the α-motor neurones reduces muscle contraction and allows it to lengthen.

The main components of mammalian muscle spindle



Each spindle has a capsule and usually contains two nuclear bag fibres and four or more nuclear chain fibres.
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Figure 1

Even though this negative feedback mechanism would, in principle, act to preserve an individual's posture, in practice it is too slow. One of the problems of the system as described so far (and this applies to feedback loops in general) is that it measures the length of the muscle and so has static sensitivity only. As we begin to lose our balance the initial error in length of the muscle is small, and so the response the feedback loop produces is small — too small to be effective. This problem is overcome by the dynamic sensitivity of the spindles. Dynamic sensitivity responds to *change* rather than *state*, and the dynamic component of the reflex comes from the Ia afferents arising from around the nuclear bags of the nuclear bag fibres. These fibres are sensitive to the rate of lengthening of the muscle, although the precise mechanism is not yet clear. Sensory nerves originating from the nuclear chain fibres show only static responses. The result of this dynamic input is that, as soon as the muscle starts to lengthen, there is a burst of activity from the afferent (nuclear bag) nerves that leads to a sufficiently large muscle contraction.

In practice the basic stretch reflex is complicated in three main ways.

- Reciprocal innervation — through a pathway involving two synapses, increased input from the Ia fibres causes inhibition of the antagonistic muscle. There is an obvious benefit in having reflex changes to antagonistic muscles behaving inversely to each other.
- Efferent fibres — the above mechanism is appropriate for maintaining posture, where the length of the muscles needs to be maintained at a set value, but a problem arises if movement, which requires a controlled contraction or relaxation, is required. β-Efferent and γ-efferent fibres pass to the ends of both nuclear bag and nuclear chain fibres and form 'plate endings' and 'trail endings' (Figure 1). These efferent fibres are of two types and can stimulate either the dynamic or static response of the muscle spindle. Changes in sensitivity of the spindle are brought about by contraction of the intrafusal fibres that stretch the area under the sensory nerve endings. If the firing of these efferent fibres increases, the increased sensory input from the spindles causes a reflex contraction of the extrafusal fibres by the normal pathway. Likewise, a decreased rate of firing of these efferents will lead to muscle relaxation. In practice, when a voluntary movement is initiated by the motor cortex, for example, there is a co-activation of the α-motor neurones (which provide the contractile force via the extrafusal fibres) and β- and γ-fibres (which change the 'set-point' of the system — the length at which the muscle is controlled by the stretch reflex). This co-activation of α-, β- and γ-fibres enables a controlled contraction or relaxation to take place. As a further example of the value of both intrafusal and extrafusal fibres, there is a high ratio of intrafusal fibres to extrafusal fibres in finely controlled muscles, such as those controlling the eye; this enables the length of these muscles and changes in length to be controlled with great accuracy. As a result, both eyes can point in exactly the same direction, as required for stereoscopic vision. The activity of the α-motor neurones and their efferent fibres is affected by several other sources, including noxious stimuli to the skin and muscle effort elsewhere in the body. For example, clasping the hands

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