Chapter 4

Motor control

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LEARNING OUTCOMES

When you have completed this chapter, you should be able to:
1. outline the roles of the various nervous system centres in the control of movement
2. explain how movements are planned, generated and controlled
3. apply understanding to specific movements (e.g. balance and gait)
4. demonstrate knowledge of information transmission within the nervous system.

INTRODUCTION

The purpose of this chapter is to help you with understanding the human nervous system and how it participates in motor control. This chapter will give you an overview that will help you get the whole picture, and you should refer to specific texts to obtain detailed information. Traditionally, this has been done by reducing the function of this complex system to the properties of its individual elements: the neurons and control centres. Although it is essential to understand the language used to describe the system and to have a basic knowledge about which elements contribute to the complex affair of human movement, this reductionist view is not sufficient, and sometimes you will have to ignore the individual elements in order to better understand the system as a whole.

One of the traditional views of the nervous system has been that it is purely hierarchical, with a
top down approach of control. According to this view, the cortical areas of the brain would exert a higher level of control and organize voluntary skilled movement. On the other end, the spinal cord would be fairly low down in the control stakes and mainly execute plans designed and refined above. A number of textbooks, such as Tortora and Derrickson (2008), Ganong (2003), Kiernan (2008) and Martini and Nath (2008), will provide you with further details. The section in this chapter on *The structures of the nervous system for controlling movement* will also give you an overview of the individual parts of the movement control system. In reality, there is, however, no real separation between voluntary movements and the background of postural control that maintains the body in an upright position with the aid of automatic reflexes and responses. See also Chapter 5 for more information on posture and balance. Therefore parallel systems of control, with integration of all levels rather than just a serial hierarchy, may be a more appropriate description. All levels of control, from the spinal cord up to the cerebral cortex, are necessary and integrated to provide the base of axial stability for more normal distal mobility and skilled or refined coordinated limb movements (Kandel et al. 2000). In addition, the environmental context and the movement task itself will influence how the nervous system organizes movement.

**ACTIVITY 4.1**

Chris reports that one of his friends at university has been involved in a car accident. He injured his leg during the accident, but his bones are now healed and he is back at university. Unfortunately, he still finds it difficult to move his foot because one of his nerves in his leg sustained an injury.

Work in small groups or on your own. Find a physiology textbook that has a diagram of peripheral nerves and find the common fibular nerve. Identify the function of this nerve and explain why Chris’s friend may find it difficult to move his foot. He also cannot feel touch or pressure over the dorsum of his foot. Explain why.

**INFORMATION TRANSMISSION**

The vast numbers of neurons in the human nervous system need to communicate with each other, often very rapidly. Information within neurons and between neurons is carried by electrical and chemical signals. The rapid transmission of signals, which is vital for human movement, is a function of the action potential. This action potential is achieved by temporary changes of current flow in and out of cells, which then propagate a signal along the nerve axon. A necessary precondition for action potentials is the creation of a membrane potential, the resting potential (Tortora and Derrickson, 2008). Please note that no movement is possible if the action potential is completely interrupted, and that movement will be impaired if the signal propagation is abnormal. This may be the case if the myelin sheath that surrounds nerve axons is damaged, such as in multiple sclerosis. Figure 4.1 shows the concentrations of ions inside and outside the nerve cell during the resting potential. Figure 4.2 shows the changes in membrane potential during the action potential. Box 4.1 summarizes the key facts about the action potential.

Information transmission from one cell to another occurs at the synapse. The most important components of a synapse are the presynaptic membrane, the synaptic cleft and the postsynaptic membrane (Latash, 2008). An action potential arrives at the presynaptic membrane. This leads to the influx of Ca\(^{2+}\), which in turn facilitates the fusion of neurotransmitter vesicles to the membrane for the release of the neurotransmitter into the synaptic cleft. Neurotransmitter molecules diffuse across the synaptic cleft and bind at specialist receptor sites in the postsynaptic neuron. This changes the potential in the postsynaptic neuron as ion channels are opened and the voltage across the cell membrane changes. Depending on the particular type of channel that is being activated, either depolarization or hyperpolarization may occur. This explains how an action potential in the presynaptic neuron can cause either excitation or inhibition of the postsynaptic membrane. Opening of Na\(^+\) channels would lead to depolarization and therefore excitation, whereas opening of the Cl\(^-\) channels would hyperpolarize the postsynaptic neuron and lead to inhibition. Figure 4.3 summarizes the events that occur at a synapse.

**ACTIVITY 4.2**

Work in small groups or on your own. Find a physiology textbook that has a diagram of peripheral nerves and answer the following question: chemical synapses such as the one shown in Figure 4.3 transmit a signal in only one direction – why?
The central nervous system (CNS) needs to receive continuous feedback about movement. It receives this information in the form of the status of muscles, i.e. length, instantaneous tension, and rate of change of length and tension (Shumway-Cook and Woollacott, 2007). Muscle spindles detect the rate and changes in the length of a muscle, whereas Golgi tendon organs detect degree and rate of change of tension. Signals from these sensory receptors operate at an almost subconscious level, transmitting information into the spinal cord, cerebellum and cerebral cortex, where they assist in the control of muscle contraction.

The muscle spindle has both a static and a dynamic response. The primary and secondary endings respond to the length of the receptor, so impulses transmitted are proportional to the degree of stretch and continue to be transmitted as long as the receptor remains stretched. If the spindle receptors shorten, the firing rate decreases.

**Figure 4.1** Distribution of ions across the cell membrane during the resting potential.

<table>
<thead>
<tr>
<th>Ion</th>
<th>Concentration intracellular fluid</th>
<th>Concentration in extracellular fluid</th>
</tr>
</thead>
<tbody>
<tr>
<td>K⁺ – Potassium</td>
<td>150 mmol/l</td>
<td>5 mmol/l</td>
</tr>
<tr>
<td>Na⁺ – Sodium</td>
<td>12 mmol/l</td>
<td>150 mmol/l</td>
</tr>
<tr>
<td>Cl⁻ – Chlorine</td>
<td>5 mmol/l</td>
<td>125 mmol/l</td>
</tr>
<tr>
<td>A⁻ – Organic anions</td>
<td>150 mmol/l</td>
<td>–</td>
</tr>
</tbody>
</table>
BOX 4.1 Summary of important facts associated with the action potential

- A necessary precondition for the creation of an action potential is the resting potential.
- The resting potential creates the excitability of the cell.
- The resting potential is the unequal distribution of ions across the cell membrane, with a negative charge of \(-70\, \text{mV}\) in the cytosol (the intracellular fluid).
- The action potential emerges if a stimulus is large enough to take the membrane potential above the threshold (\(-55\, \text{mV}\)).
- When the threshold level is reached, voltage-gated Na\(^+\) channels open and Na\(^+\) rushes into the cell, which produces the depolarization period.
- Voltage-gated K\(^+\) channels open to allow K\(^+\) to flow out of the cell and produce the repolarization period.
- Another action potential cannot be generated during the depolarization period and during most of the repolarization period.
- The action potential propagates along the axon segment by segment until it reaches the synaptic end bulb at the end of the axon.
- Propagation is more rapid in myelinated axons, where the signal leaps from node to node. Large-diameter axons also propagate signals faster than small-diameter axons.
- Axons of sensory neurons transmitting information about touch, pressure and movement, as well as the axons of motor neurons transmitting movement instructions to the skeletal muscles, are all large and myelinated.
Only the primary endings respond to sudden changes of length by increasing their firing rate, and then only while the length is actually increasing. Once the length stops increasing, the discharge returns to its original level, although the static response may still be active. If the spindle receptors shorten, then the firing rate decreases.

Control of the static and dynamic response is by the gamma motor neuron. Normally, the muscle spindle emits sensory nerve impulses continuously, with the rate increasing as the spindle is stretched (lengthened) or decreasing as the spindle shortens.

The spinal reflexes associated with the muscle spindle and Golgi tendon organ are the stretch reflex and the tendon reflex, respectively. Stimulation of the stretch reflex leads to a reflex contraction of the muscle that has been stretched, whereas the tendon reflex will lead to a reflex relaxation of the muscle if there is tension build-up. Both reflexes have a protective function.

The stretch reflex also has the ability to prevent some types of oscillation and jerkiness of body movements even if the input is jerky, i.e. a damping function (Hall, 2005).

When the motor cortex or other areas of the brain transmit signals to the alpha motor neurons, the gamma motor neurons are nearly always stimulated simultaneously, i.e. a coactivation of the alpha and gamma systems so that intra- and extrafusal muscle fibres (usually) contract at the same time. This stops the muscle spindle opposing the muscle contraction and maintains a proper damping and load responsiveness of the spindle regardless of change in muscle length. If the alpha and gamma systems are stimulated simultaneously and the intra- and extrafusal fibres contract equally, then the degree of stimulation of the muscle spindle will not change. If the extrafusal fibres contract less because they are working against a great load, the mismatch will cause a stretch on the spindle, and the resultant stretch reflex will provide extra excitation of the extrafusal fibres to overcome the load (Cohen, 1998).

The gamma efferent system is excited or controlled by areas in the brainstem, with impulses transmitted to that region from the cerebellum, basal ganglia and cerebral cortex.

The Golgi tendon organ, as a sensory receptor in the muscle tendon, detects relative muscle tension. Therefore it is able to provide the CNS with instantaneous information on the degree of tension of each small segment of each muscle. The Golgi tendon organ is stimulated by increased tension. When the increase in tension is too great, the tendon reflex response is evoked in the same muscle, and this response is entirely inhibitory. The brain dictates a set point of tension beyond which automatic inhibition of muscle contraction prevents additional tension. Alternatively, if the tension decrease is too low, then the Golgi tendon organ reacts to return the tension to a more normal level. This leads to a loss of inhibition, so allowing the A-alpha motor neuron to be more active and increase the muscle tension.

Box 4.2 lists key facts about receptors and reflexes.

### BOX 4.2 Summary of important facts associated with receptors and reflexes

- Sensory feedback for movement control is mainly provided by receptors inside the muscle and between the muscle and tendon.
- The receptors are the muscle spindle and the Golgi tendon organ.
- The muscle spindle provides information about muscle length changes.
- The Golgi tendon organ provides information about tension changes.
- Both of these receptors are also closely linked to spinal reflexes.
- The stretch reflex relies on muscle spindle information and is triggered when a muscle is lengthened. It is designed to prevent overstretching of a muscle by causing a reflex contraction of the lengthened muscle.
- The tendon reflex relies on Golgi tendon information and is triggered when tension is building up at the interchange of muscle and tendon. It is designed to prevent tearing of a muscle by causing a reflex relaxation of the muscle.
- Stretch reflex and tension reflex therefore have opposite effects on a muscle.
MOTOR CONTROL

CONTROLLING ‘SIMPLE’ MOVEMENTS

Human movement is anything but simple. There is infinite variability, and any attempt to describe a complex system in simple terms is likely to tell you only part of the story. However, if you understand the ‘simple’, then you are more likely to grasp the more complex.

Most human voluntary movements require the design and planning of that movement by a control centre. This control centre will use previous experiences in the planning of movements. Once a movement plan has been designed, it will be supplied as a signal by the control centre in a feed forward manner to an execution centre responsible for activating muscles to produce the movement. Feed forward implies that the signal is independent of the output or any other variable (Latash, 2008). The feed forward signal uses knowledge of the dynamics of the musculoskeletal system and the environment it is in (Stroeve, 1999). Once the movement has started, receptors will be able to provide feedback about the movement. The controller may then be able to alter the signal according to this feedback. The addition of a comparator centre provides a mechanism to speed up the refinement of movement according to its feedback. Over a period of time, the feedback will in turn influence the feed forward signal designed by the control centre and motor learning will have taken place (Houk et al. 1997). It may be worth visiting Chapter 6 (Motor Learning) before you move on. Figure 4.4 shows such a simple movement control system using feed forward and feedback mechanisms.

POSTURAL CONTROL AND BALANCE

Postural control and balance involve controlling the body’s position in space for stability and orientation (Shumway-Cook and Woollacott, 2007). The nervous system participates in postural control by designing command signals and by providing feedback through a number of receptors. The interpretation and integration of all the feedback signals would also be undertaken by the nervous system. The postural control requirements vary with the task. For example, sitting in a chair and watching television requires minimal stability control, whereas standing on one leg and watching television is a lot more demanding on the postural control system.

Therefore, we need to have a flexible control system that can adapt to these varying demands. Like the simple movement system above, postural control requires the production of movements or muscular contractions that help keep the body upright in space. Like the simple movement system above, postural control is also achieved by a combination of feed forward and feedback mechanisms. The control centre for posture will utilize previous experiences. These previous experiences will contribute to an internal representation of the body or body schema (Massion, 1994). This body schema provides reference points for body alignment, movement and orientation in space. The aim of the nervous system is then to maintain this body schema during changes in the environment or during movement. The feedback mechanisms for posture and balance involve more
than just the receptors for movement in the muscles. In addition, there will be feedback about movements of the head through the vestibular system in the inner ear, visual feedback, and feedback about pressure changes through the support surfaces of the body (Kandel et al. 2000). The feed forward mechanisms will have to include signals that are able to anticipate disturbances to the postural control system that will arise as a consequence of movement (Aruin et al. 2001). Figure 4.5 shows the system of feed forward and feedback for the control of posture and balance. Please read Chapter 5 for more detailed exploration of these issues.

**GAIT**

Walking requires the cooperation of a large number of muscles and joints. Research on animals has shown that a neural network in the spinal cord is responsible for regulating the stepping motions during gait. There is controversy about whether such a network also exists in humans (Vilensky and O’Connor, 1997; Guadagnoli et al. 2000).

The brainstem, together with the spinal cord, could provide such a network or central pattern generator to coordinate locomotion. The impulse for walking may come from higher cortical centres, but these central pattern generators could provide the motor pattern for walking. Figure 4.6 provides a proposed diagram of a central pattern generator for movement in the lamprey fish (Grillner et al. 1995). A similar neural network may also exist in humans. It may be worth also visiting Chapter 11.

Box 4.3 lists key facts about the nervous system and movement.

**THE STRUCTURES OF THE NERVOUS SYSTEM FOR CONTROLLING MOVEMENT**

This chapter has so far given you an overview of how the nervous system controls all types of movement and how the necessary signals for this control are generated and propagated. This has been the difficult part of the chapter, and once you have understood that, you should move on to the next part. This part will add some more detail about
Feedback from muscle spindles provide feedback of movement which can provide further excitatory stimuli ipsilaterally or inhibitory signals contralaterally.

**Figure 4.6** Hypothetical model of a central pattern generator for locomotion. (After Grillner et al. 1995, with permission.)

**BOX 4.3** Key factors relating to the nervous system and movement

- The nervous system as a whole controls all types of movement.
- These movements can differ in complexity and characteristics. They can range from a relatively simple contraction of a muscle over one joint to multijoint and whole body movements such as those used during walking.
- Voluntary movements are designed utilizing previous experiences and use feed forward signals towards the muscles.
- In addition to the feed forward signals, there will also be feedback about movement and the body in relation to the environment.
- All voluntary movements, including posture, balance and gait, are based on these feed forward and feedback principles.
- The feedback generated through movement experience also provides for the possibility of motor learning.
the individual parts of the nervous system, which have been described only in very broad terms up until now. For example, you will find that the comparator centre described in Figure 4.4 is in reality called the cerebellum.

**Cerebral cortex**

The cerebral cortex is the main centre for the control of voluntary movement. It uses the information it receives from the cerebellum, basal ganglia and other centres in the CNS, as well as the feedback from the periphery, to bring movements under voluntary control.

The cerebral cortex, or more specifically the association areas of the cerebral cortex, provides the advanced intellectual functions of humans, having a memory store and recall abilities along with other higher cognitive functions. The cerebral cortex is, therefore, able to perceive, understand and integrate all the various sensations. This provides the transition from perception to action (Shumway-Cook and Woollacott, 2007). Its primary movement function is in the planning and execution of many complex motor activities, especially the highly skilled manipulative movements of the hand. This fact becomes clear when one considers the size of a cortical area for a particular part of the body.

The motor cortex occupies the posterior half of the frontal lobes. It is a broad area of the cerebral cortex concerned with integrating the sensations from the association areas with the control of movements and posture. It is closely related to other motor areas, including the primary motor area and the premotor or motor association area. The primary motor area contains very large pyramidal cells that send fibres directly to the spinal cord and anterior horn cells via the corticospinal pathways. In contrast, the premotor area has a few fibres connecting directly with the spinal cord, but it mainly sends signals into the primary motor cortex to elicit multiple groups of muscles, i.e. signals generated here cause more complex muscle actions usually involving groups of muscles that perform specific tasks, rather than individual muscles. This area connects to the cerebellum and basal ganglia, which both transmit signals back, via the thalamus, to the motor cortex. Projection fibres from the visual and auditory areas of the brain allow visual and auditory information to be integrated at cortical level to influence the activity of the primary motor area.

Each time the corticospinal pathway transmits information to the spinal cord, the same information is received by the basal ganglia, brainstem and cerebellum. Nerve signals from the motor cortex cause a muscle group to contract. The signal then returns from the activated region of the body to the same neurons that caused the contraction, providing a general positive feedback enhancement if the movement was successful and recording it for future use. The role of the cerebral cortex and its subdivisions is described in Figure 4.7.

**Basal ganglia**

The basal ganglia consist of five nuclei deep inside the brain (putamen, caudate nucleus, globus pallidus, subthalamic nucleus and substantia nigra). They serve as side loops to the cerebral cortex, because they receive their input from the cerebral cortex and project exclusively back to the cerebral cortex. The basal ganglia are involved in all types of movement but have a predominant role in the provision of internal cues for the smooth running of learned movements (Morris and Iansek, 1996).

It is believed that the basal ganglia play an essential role in the selective initiation of most activities of the body as well as the selective suppression of unwanted movements. A number of distinct loops have been described, and the interconnections of inhibitory or excitatory neurotransmitters explain the variety of symptoms that emerge in disorders of the basal ganglia. The direct pathway is responsible for the facilitation of movement, whereas the indirect pathway is more involved in the inhibition of unwanted movements (Rothwell, 1994). Figure 4.8 shows the direct loop through the basal ganglia.

**Cerebellum**

The cerebellum is vital for the control of very rapid muscular activities such as running, talking, typing, playing sport or playing a musical instrument. Loss of the cerebellum leads to incoordination of these movements such that the actions are still available but no longer rapid or coordinated. This is caused by the loss of the planning function.

The cerebellum makes comparisons between the movement plan and output and can change movement signal if there is a discrepancy.

Extensive input and output systems operate to and from the cerebellum. Input pathways to the cerebellum from the cerebral cortex, carrying both
motor and sensory information, pass through various brainstem nuclei before reaching the deep nuclei of the cerebellum. Likewise, output from the cerebellum exits via the deep nuclei to the cerebral cortex to help coordinate voluntary motor activity initiated there.

The cerebellum does not initiate motor activities but plays an important role in planning, mediating, correcting, coordinating and predicting motor activities, especially for rapid movements. It is vitally important for the control of posture and equilibrium, when it works in close relationship with the brainstem. Working with the basal ganglia and thalamus, the cerebellum helps to control voluntary movement by utilizing feedback circuits from the periphery and the brain. The distal parts of the limbs are controlled by information from the motor cortex and from the periphery, and this information is integrated in the cerebellum. This provides smooth, coordinated movements of agonists and antagonistic muscle groups, allowing the performance of accurate, purposeful intricate movements, which are especially required in the distal part of the limbs. This is achieved by comparing the intentions of the higher centres of the motor cortex with the performance of respective parts of the body. Overall, the cerebellum serves as an error-correcting device for goal-directed movements.

**Brainstem**

The principal role of the brainstem in control of motor function is to provide background contractions of the postural muscles of the trunk, neck
and proximal parts of limb musculature, so providing support for the body against gravity. The relative degree of contraction of these individual antigravity muscles is determined by equilibrium mechanisms, with reactions being controlled by the vestibular apparatus, which is directly related to the brainstem region.

The brainstem connects the spinal cord to the cerebral cortex. It is comprised of the midbrain, pons and medulla oblongata. The central core of this region is often referred to as the reticular formation. This region of the CNS comprises all the major pathways connecting the brain to the spinal cord in a very compact, restricted space. It is also the exit point of the cranial nerves from the CNS.

It is through the integration of the information reaching the reticular formation that axial postural control and gross movements are controlled. Input to the reticular formation is from many sources, including the spinoreticular pathways, collaterals from spinothalamic pathways, vestibular nuclei, cerebellum, basal ganglia, cerebral cortex and hypothalamus. The smaller neurons make multiple connections within the area, whereas the larger neurons are passing through, being mainly motor in function.

The vestibular nuclei are very important for the functional control of eye movements, equilibrium, support of the body against gravity, and the gross stereotyped movements of the body. The direct connections to the vestibular apparatus of the inner ear and cerebellum, as well as the cerebral cortex, enable the use of preprogrammed, background attitudinal reactions to maintain equilibrium and posture. Working with the pontine portion of the reticular formation, the vestibular nuclei are intrinsically excitable; however, this is held in check by inhibitory signals from the basal ganglia (Hall, 2005). Overall, the motor-related functions of the brainstem are to support the body against gravity; generate gross, stereotyped movements of the body; and maintain equilibrium. This is achieved in association with the cerebellum, basal ganglia and cortical regions.

Sensory signals enter the cord through the sensory nerve roots and then travel to two separate destinations:

1. same or nearby segments of the cord, where they terminate in the grey matter and elicit local segmental responses (excitatory, inhibitory, reflexes etc.)

2. higher centres of the CNS, i.e. higher in the cord, and brainstem cortices, where they provide conscious (and unconscious, i.e. cerebellum) sensory information and experiences.

Each segment of the cord has several million neurons in the grey matter, which include sensory relay neurons, anterior motor neurons and interneurons.

Interneurons are small and highly excitable, with many interconnections either with each other or with the anterior motor neurons. They have an integrative or processing function within the spinal cord, as few incoming sensory signals to the spinal cord or signals from the brain terminate directly on an anterior motor neuron. This is essential for the control of motor function. One specific type of interneuron is called the Renshaw cell, located in the anterior horn of the spinal cord. Collaterals from one motor neuron can pass to adjacent Renshaw cells, which then transmit inhibitory signals to nearby motor neurons. So stimulation of one motor neuron can also inhibit the surrounding motor neurons. This is termed recurrent or lateral inhibition. This allows the motor system to focus or sharpen its signal by allowing good transmission of the primary signal and suppressing the tendency for the signal to spread to other neurons (Rothwell, 1994). Together with the brainstem, the spinal cord contains a network of neurons that control walking. Figure 4.9 shows the basic components of a spinal reflex pathway.

**ACTIVITY 4.3**

Agnes tells Chris that she has a friend who has difficulties moving her left arm and also her left leg. She wonders if this may be similar to the problem Chris’s friend has.

Work in small groups or on your own. Find a neurology textbook and identify the symptoms following a stroke. Explain why Agnes’s friend has movement problems on the left side of her body. Which part of the nervous system has been affected?
CONTROL PROCESSES OF VOLUNTARY MOVEMENT

Figure 4.10 summarizes in a simplistic diagram the control processes for voluntary movement. Follow the arrows and boxes from the design to the execution and then the return of feedback, which is finally stored as memory traces.

1. The cortical association areas play the key role in the design and planning of voluntary movements. Action potentials from the cortical association areas project to the basal ganglia for refinement and selective activation of movements and/or inhibition of unwanted movements.

2/3. The thalamus here is part of the basal ganglia loops and sends impulses to the motor cortex, which is seen as the final common pathway.

4. Impulses from the motor cortex are almost simultaneously sent to the cerebellum, the brainstem and the spinal cord. The cerebellum will use this information to compare it with the movement sensory information received from the periphery (6). The brainstem will play a role in maintaining background postural control, while impulses to the spinal cord are more of a focal nature for the activation of individual muscles or groups of muscles.

5. Alpha motor neurons cause muscle contraction.

6. The sensation of movement, together with other relevant feedback information, is sent towards the CNS. This sensory information is needed by various centres. The spinal cord will use it in its integration of spinal reflexes and the control of walking patterns. The brainstem utilizes sensory feedback mostly for postural control and balance. Sensory feedback is also sent to the thalamus. The cerebellum compares the movement as it occurs with the original movement instruction sent by the motor cortex.

7. If there is a discrepancy between the intended movement and the actual movement, correcting signals can be sent directly to the execution centres.

8. The thalamus distributes sensory feedback to its appropriate location on the sensory cortex.

9. Sensory experiences are interpreted by the cortical association areas, and memorized movements are stored for future use in the design and planning of movements.

Figure 4.9 The components of a basic spinal reflex pathway, using the stretch reflex as an example.

1. Sensory organ
   A muscle is lengthened passively and this is sensed by the muscle spindle

2. Sensory neuron
   The sensory neuron carries the action potential to the posterior horn in the spinal cord

3. Integrating centre
   The spinal cord acts as integrating centre, passing the information either directly, or indirectly via interneurons, to the motor parts of the reflex pathways

4. Motor neuron
   An instruction to contract a muscle is sent via a motor neuron

5. Effector organ
   The muscle which was originally lengthened contracts in order to prevent over-lengthening
References


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