Structure and function of neurons

The focus of this essay is to give an account of the structure and function of a neuron. A neuron is a solitary specialized cell often found to be part of a neural circuit working within the nervous system. It serves the purpose of propagating signals and provoking responses along the nervous system (Khan Academy, 2018). Neurons differ from most other cells in that most neurons cannot divide after differentiation, as a result once matured if a neuron in the central nervous system has been destroyed it often cannot be replaced (Nicholls et al., 1992.). It is critical to note that the function of the neuron cannot be understood without considering the structure and function of its basic component parts which shall be explored within this essay. In addition, this essay will also look to explore: neuronal classification, neurons ability to transform any kind of signal into an electrical current, and their ability to propagate these signals to provoke a response.

To begin with, we shall explore the structure of a neuron in order to be able to later understand how it can carry out its functions. All neurons obtain a soma, containing the same organelles found in all animal cells. These organelles, however, vary in amount within the soma of a neuron compared to other cells as a reflection of the cell's specific functions. For instance, the volume of rough endoplasmic reticulum in neurons is richer than glia and other non-neuronal cells. Also present within the soma is cytosol a salty potassium rich fluid within the soma separated from the outside by the neuronal membrane its role shall be briefly be explored farther on. The neuronal membrane encloses the cytoplasm inside and excludes other material within the extracellular fluid bathing the cell. An important feature to this structure is that it is studded with proteins, for example, protein pumps and pores which regulate what substances can enter or exit the cell (Bear, Connors and Paradiso, 2016).

The cytoskeleton is the scaffolding providing the neurons' characteristic shape, consisting of three types that shall briefly be delved into. Firstly, microtubules are the largest scaffolding unit and run longitudinally down neurites. It is made of polymer strands of tubulin and as a result neuronal shape can be altered by polymerization or depolymerization. Microfilaments are a similar thickness to the cell membrane and found throughout the neuron. They're made of two thin strands of a polymer formed out of the protein actin braided together and are closely associated to the membrane. Like microtubules they also run longitudinally. They're believed to aid the changing of cell shape and are involved in the mechanisms of muscle contraction. In addition to usual scaffolding that cells have, neurons in addition have their own more minor scaffolding components known as neurofilaments which provide mechanical strength to the neuron. (Bear, Connors and Paradiso, 2016).

Within nature there is an established relationship between structure and function- nerve cells are one prominent example due to the formation of excessive communication networks. As a result, the usual spherical structure of the cell has become elongated and deformed (Al-Chalabi, Delamont and Turner, 2008). Unique to neurons is the protrusions stemming from the soma required for the receiving and sending of electrical signals making neuronal connection possible. Dendrites are tree-like structures extending from the soma functioning as the antennae of the cell. They are sometimes covered with dendritic spines, that are believed to play a role in isolation of various chemical reactions. These spines are sensitive towards both type and amount of synaptic activity, as an implication, unusual changes to the spines have been shown to impair the function of cognitive capabilities. (Bear, Connors and Paradiso, 2016). For example, Migulel Marin-Padilla and Dominick Purpura (1970) examined the brains of intellectually disabled children using Golgi staining. They discovered low functioning children were found to have fewer dendritic spines and those they did have where misshapen (unusually long and thin). Suggesting intellectual disability reflects on failure of typical structures and circuits forming in the brain (Marin-Padilla and Purpura, 1970 as cited in Bear, Connors and Paradiso, 2016. Pg. 47).

Most nerve cells have one long extension called an axon beginning with a region named the axon hillock. Protein composition throughout the axon is different to that in the soma and neuronal membrane, consequently no protein synthesis takes place here. The axon often forms axon collaterals, these extensions allow the axon to advance considerable distances and carry out its function in communicating with numerous parts of the nervous system. The diameter of the axon is variable ranging from 1µm- 25µm this structural variance is important as it affects the rate of which a nerve impulse can travel. Finally, th axon ends in an axon terminal; the site of synaptic transmission. There are structural differences present here such as: lack of microtubules, synaptic vesicles, inner membrane surface facing synapse densely covered with proteins and its cytoplasm containing many mitochondria. Synaptic transmission of information involves the electrical impulse to be converted into a chemical signal resulting in the release of neurotransmitters stored in the synaptic vesicles. This chemical signal is then converted back to an electrical impulse at the postsynaptic membrane. Modification of this process is involved in functions such as learning and or memory (Bear, Connors and Paradiso, 2016). Sometimes axons are myelinated by either Schwann or oligodendrocytes. This myelination is electrically insulating and has gaps called nodes of Ranvier which allow faster rates of conduction of signals by saltatory insulation (Goetz, 2007).

Neuronal cells can be classified according to both morphology and or functional characteristics. Morphology classification include granule cells these are grain like in shape as they have small cell bodies. Another example is stellate cells these are small interneurons that have a star shaped dendritic tree. They can function as either inhibitory if dendrites are aspinous and excitatory if spinous (Furness, 2018). A contextual example within the mammalian cerebral cortex and hippocampus is the pyramidal neuron. These neurons have a pyramid shaped cell body, with an apical dendrite and several basal dendrites branching extensively to produce a dense dendritic tree. This tree allows many contact points to be created and is covered in spines in close contact to presynaptic terminals of partnering cells (Luo, 2016).

Neurons are also frequently classified by their function. Such as sensory neurons, afferent neurons which carry information about the internal and external world to the central nervous system. They occur in places such as specialized sense organs: eyes, inner ear, skin, nose, tongue, joints. They exhibit specific characteristics in their structure with long dendrites to make many contact points to obtain information from internal or external stimuli and short axons they are pseudo unipolar (Luo, 2016). Examples include visual neurons, cells that respond to light entering the eye and auditory neurons, cells that respond to sound entering the ear. Motor neurons are effect neurons whose function is to carry signals out of the central nervous system to target effector organs such as muscles and glands. Their structure is characterized by short dendrites and long axons allowing them to extend far distances across the body in order to provoke responses. For example, motor neurons found in the spinal cord extend their bushy dendrites within the spinal cord from the spinal cord and project out their axon into muscle. Lastly interneurons can be afferent or efferent and function to convey signals from one neuron to another. They consist of short dendrites and either long or short axons (Psychology Hub, 2018).

Neurons perform their functions in the context of neural circuits; interconnected neurons acting collectively to perform specific functions. An example in vertebrates is those mediating spinal reflexes which can consist of as few as two interconnected neurons. One such reaction is the knee-jerk reaction. Where a sensory neuron detects stretch of muscle spindles caused by impact and convert the mechanical stimuli into an electrical impulse. Two specific functions of neurons are displayed in this example, firstly, is the neurons ability to receive information and secondly, to communicate signals to target cells. The central and peripheral axons of sensory neurons propagate these electrical signals back to the spinal cord in the form of action potentials. In the spinal cord central axons of the sensory neuron establish synaptic connections with dendrites of the motor neurons which terminate at the same extensor. As a result, the action potential from the motor neuron causes the release of neurotransmitters at the motor axon terminal causing contraction. In this case the sensory and motor neurons are excitation however the contraction of a muscle requires coordination as they are antagonistic. Therefore, along with causing the contraction in extensor muscle sensory axons must also inhibit contraction of corresponding flexor muscle. This inhibition is mediated by inhibitory interneurons in the spinal cord (Luo, 2016).

A key function of nerve cells is their ability to convert a signal of almost any kind into an electrical current; most commonly is the transformation of chemical to electrical. All neurons have a resting potential- where the inside of the cell is negative in respect to the extracellular solution. A change in potential therefore propagates an electrical signal which can fall into two dominant classes. The first is called local graded potentials these vary in amplitude depending on the activating stimuli and often only spread short distances from stimulus site. The second category is known as action potentials these are initiated when the localized graded potential is sufficiently large and can depolarize the cell membrane beyond its threshold value (Peterson, 2018). A vital function of neurons is the ability to differentiate the strength of a stimulus and therefore if it is worthy of provoking a response in a very short time period. Action potentials can travel large distances across the body however lack flexibility in amplitude and duration (Nicholls et al., 1992.). It is notably an all-or-nothing event. Action potentials see the rapid membrane depolarization and repolarization; originating in the axon hillock which that contains many sodium and potassium voltage channels. A stimulus causes a change to the nerve cell such as nerve fibres being stretched (Luo, 2016) which then can cause sodium channels to open. As a result, sodium floods into the cell under its diffusion gradient. This results in the final potential of the cell being 30+mV. Sodium channels soon close while potassium channels open causing an undershoot where potential difference hits -85mV. Around this time the sodium-potassium pump regains its function in moving sodium out of the cell and potassium in, in order to preestablish resting potential (Khan Academy, 2018) The action potential propagates down to the axon to the terminal where the electrical impulse is transmitted via an electric or chemical synapse. If it is a chemical synapse a neurotransmitter will be released. (Lodish H, Berk A, Zipursky SL, et al., 2000.). Propagation of the action potential takes place by a process called positive feedback, in which the segment immediately in front of the depolarized section electrically attracts sodium ions. As a result, this immediate section then also gets depolarised (Caurana, 2018)

In conclusion there are obvious structural differences in neurons are compared to other animal cells, such as their ‘ deformed’ shape and extensions (axons and dendrites). There are also structural differences in the organelles they contain and their cytoskeleton which was described. It can additionally be noted that neurons carry out an extensive role in the communication of signals allowing us to respond to both external and internal stimuli. Functional neurons where explored and the involvement of neural circuits as well as an example was given to illustrate the vital role neurons play. This function is of huge importance in our ability to survive. Propagation of signals in the form of action potentials was explored as this is a vital function of neurons along with their ability to convert electrical signals to chemical and then back to electric. Therefore, it can be concluded that neurons have three basic functions to receive information, integrate incoming signals and communicate signals to target cells.

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