The cells of the nervous system

Neurons

- The nervous system is made up of a system of nerve cells, known as neurons, which transmit electrical signals called nerve impulses.
- Glial cells support and maintain these neurons.

Structure of neurons

- All neurons have the same basic structure, they are composed of three key structures:
  - dendrites
  - a cell body
  - axons

- Nerve impulses always travel in the same direction:
The cells of the nervous system and neurotransmitters

- **Cell body** - The cell body contains a nucleus and cytoplasm.
  - The nucleus codes for neurotransmitter. The nucleus also codes for the enzyme which makes or breaks down the neurotransmitter. The nucleus codes for receptors on the post synaptic neuron.
  - The cytoplasm contains organelles such as mitochondria to provide energy for impulses and ribosomes which synthesise proteins (e.g. enzymes) for the synthesis of neurotransmitters.
- **Dendrites** – these fibres receive nerve impulses and carry them towards the cell body.
- **Axon** – this fibre carries nerve impulses away from the cell body.
- A neuron in a newly-born child has fewer dendrites and synaptic knobs.
- The axons of neurons are surrounded in a layer of fatty material known as the myelin sheath.
- The **myelin sheath** greatly increases the speed of transmission of a nerve impulse.
- Myelination (the extent to which an axon is covered in myelin) is not complete at birth.
- As a child ages, myelination increases and so does nervous control. **Some diseases, such as Polio, Tay-Sachs and Multiple Sclerosis (MS) can damage the myelin sheath and result in loss of muscular co-ordination.**
- Since there are fewer dendrites and less myelin sheath, the responses of a two year old child are slower than those of an adult.
- The impulses travel at a slower rate.
- Fewer impulses reach the synaptic cleft.
- Fewer connections are made to other nerve cells.
Higher Human Biology
Unit 3 Notes
The cells of the nervous system and neurotransmitters

• Less neurotransmitters released into the synaptic cleft

Types of neurons

• There are three main types of neuron:
  – sensory neuron
  – inter neuron
  – motor neuron

• Each of these neurons has adapted to suit their function.

Sensory neuron

• Has dendrites in contact with sense organs.
• These dendrites merge to form a myelinated fibre which carries impulses to the cell body.
• Has a short axon
• Forms connections with neurons in the CNS

Inter neuron

• Connects sensory neurons to motor neurons.
• Has many dendrites which form many complex, connections.
Motor neuron

- Has short dendrites which connect to neurons in the CNS
- Has a long myelinated axon
- Axon carries nerve impulses to muscle connections.
Glial cells

- Glial cells have a number of key functions:
  - physically support neurons
  - produce the myelin sheath
  - control the chemical composition of the fluid surrounding the neuron and so maintain a homeostatic environment.
  - remove debris by phagocytosis

Neurotransmitters at synapses

Synapse

- The tiny area between the ending of the an axon of one neuron and the dendrite of another is known as a synapse.
The cells of the nervous system and neurotransmitters

- The plasma membranes of each neuron are in very close contact and are separated by a narrow space called a synaptic cleft.
- Messages are passed across synaptic clefts by chemicals called neurotransmitters.
- Neurotransmitters can also relay messages from nerve to muscle as well as nerve to nerve.
- Two examples are acetylcholine and norepinephrine (also known as noradrenaline).
- The neuron before the synaptic cleft is known as the presynaptic neuron.
- The neuron after the synaptic cleft is known as the postsynaptic neuron.

Action of neurotransmitters

- The presynaptic knob contains many mitochondria to provide ATP for synthesis of neurotransmitters.
- When a nerve impulse passes through a neuron and reaches the end of the axon (known as the axon terminal), many vesicles containing neurotransmitters are stimulated.
The cells of the nervous system and neurotransmitters

- These vesicles move to and fuse with the membrane at surface of the axon terminal. The neurotransmitters within the vesicles are then released (by **exocytosis**) into the synaptic cleft.

- The neurotransmitter then diffuses across the cleft and binds to receptor molecules on the dendrites of the next neuron; this transmits the impulse to the next neuron.

- Neurotransmitters must be rapidly removed as soon as the impulse has been transmitted for the following reasons:
  - to prevent continuous stimulation of the postsynaptic neuron
  - so that the membrane is sensitive to the next stimulus
  - otherwise, the neurotransmitter would continue to have an effect
  - this allows a neurone to send many separate impulses allowing a variety in the rate of impulse transmission.

- Neurotransmitters can be removed from the synaptic cleft by:
  - enzyme degradation - this occurs with acetylcholine, the products of which are absorbed and used to synthesise new neurotransmitters

  or
The cells of the nervous system and neurotransmitters

- re-uptake - this occurs with norepinephrine, which is reabsorbed by presynaptic membrane.

- The continual synthesis and removal of neurotransmitters requires a very large amount of energy.

- Neurones contain a large number of mitochondria to provide ATP.

- This is why the brain is so easily damaged by oxygen deprivation.

**Excitatory & inhibitory signals**

- The receptor cells found on the postsynaptic neuron will determine whether the signal is:
  - excitatory (causes an increase in action e.g. cause muscles to contract) or
  - inhibitory (cause a decrease in action e.g. slow heart rate)

**Weak stimuli**

- A nerve impulse will only be transmitted across a synaptic cleft it causes the release of a sufficient number of neurotransmitter molecules; this is known as the threshold.

- Weak stimuli are known as sub-threshold stimuli and are too weak to cause the transmission of a nerve impulse.

- When the stimulus is weak, the synapse acts as a gap which the impulse cannot cross and the stimulus is ‘filtered out’ due to insufficient secretion of neurotransmitters.
Summation

- A single weak stimulus will not trigger the release of enough neurotransmitters to cause transmission of a nerve impulse.

- However, a series of weak stimuli from many neurons can bring about an impulse.

- The cumulative effect of a series of weak stimuli which triggers an impulse is known as summation.

- If a weak stimulus passed along one axon this would not trigger enough neurotransmitters to be released to reach the threshold.

- When many axons release their neurotransmitter at the same time or in rapid succession, this releases enough chemical to fire a response.

New born child

- Since there are fewer dendrites and less myelin in a new born child, fewer, slower impulses reach the synaptic cleft.

- The threshold is less likely to be reached and less neurotransmitters released into the synaptic cleft.

- There will be fewer connections to other nerve cells.
Neural Pathways

Complex neural pathways

- Neurons are connected to others in many different ways in the CNS.
- This allows many complex interactions to occur between neurons and so allows the nervous system to carry out many complex functions.
- There are three main neural pathways:
  - converging
  - diverging
  - reverberating

1. **Converging neural pathways**

- Converging neural pathways have many neurons coming together and feeding impulses to **one** neuron.
- This allows for signals to be brought together for a combined or concentrated effect (e.g. summation) at one neuron.
- *An example of this can be found with the convergence of the neurons from rod cells in the retina of the eye.*
2. **Diverging neural pathways**

   - Diverging neural pathways have one neuron branching out and feeding impulses to **many** neurons.

   - This allows for signals from a single source to be sent to several destinations, **at the same time** and allows us to co-ordinate control (e.g. when threading a needle).

3. **Reverberating neural pathways**

   - Reverberating neural pathways possess neurons later in the pathway which form connections with neurons earlier in the pathway.

   - This allows for nerve impulses to be recycled and repeatedly stimulate the circuit, these impulses will only stop when they are no longer required.

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**Plasticity of response**
The cells of the nervous system and neurotransmitters

• The ability of brain cells to become altered and form new neural pathways as a result of new environmental experiences is known as plasticity of response.

• This allows new neural pathways to be formed during early development when learning many new skills.

• Major plasticity of response can occur after brain damage (e.g. stroke) and allows undamaged cells to form new neural pathways to take on the functions of the damaged area.

• Minor plasticity is used to suppress reflexes (e.g. blinking or prevent the body dropping a hot object) or suppress sensory responses (such as visual distractions).

Neurotransmitters, mood and behaviour

Endorphins

• Endorphins are neurotransmitters which act like natural painkillers by stimulating neurons which are involved in reducing the intensity of pain.

• Endorphin production increases in response to:
  – severe injury
  – prolonged and continuous exercise
  – physical & emotional stress
  – certain foods
    • (e.g. chocolate and chilli peppers)
• Increased levels of endorphins can also bring about other responses within the body, such as:
  – euphoric feelings (intense happiness)
  – regulation (modulation) of appetite
  – release of sex hormones

**Dopamine**

• Dopamine is a neurotransmitter which induces the feeling of pleasure.

• Dopamine is also involve in reinforcing beneficial behaviour (such as satisfying hunger by eating) by activating the reward pathway.

• The reward pathway involves neurons which secrete or respond to dopamine.
Neurotransmitter related disorders

- Below are some examples of neurotransmitter related disorders:

<table>
<thead>
<tr>
<th>Disorder</th>
<th>Cause</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alzheimer's disease</td>
<td>Loss of cells synthesising acetylcholine.</td>
<td>Cholinesterase inhibitors</td>
</tr>
<tr>
<td>Parkinson's disease</td>
<td>Loss of dopamine synthesising neurons.</td>
<td>Monamine oxidase inhibitors and the potential use of adult stem cells</td>
</tr>
<tr>
<td>Schizophrenia</td>
<td>Overactive dopamine system</td>
<td>The use of dopamine antagonists</td>
</tr>
<tr>
<td>General anxiety disorders</td>
<td>Imbalance in serotonin and norepinephrin</td>
<td>The use of GABA agonists and beta blockers</td>
</tr>
<tr>
<td>Depression</td>
<td>Low levels of serotonin</td>
<td>Norepinephrine re-uptake inhibitors and monoamine oxidase enzyme inhibitors</td>
</tr>
</tbody>
</table>

- Many drugs which treat neurotransmitter related disorders are similar to neurotransmitters.

Treatment Drugs

Agonists

- Agonists are chemicals that bind to and stimulate specific receptors on postsynaptic neurons.

- Agonists mimic the action of natural neurotransmitters and so normal cell responses occur (i.e. nerve impulse is transmitted).

Antagonists

- Antagonists are chemicals that bind to and block specific receptors on postsynaptic neurons.

- Antagonists, by blocking the receptor sites, prevent the normal neurotransmitter from acting.
Higher Human Biology
Unit 3 Notes

The cells of the nervous system and neurotransmitters

• Antagonists can greatly reduce or even stop the normal transmission of nerve impulses.

• Other drugs, known as inhibitors, inhibit the enzymes which degrade neurotransmitters or inhibit re-uptake.

• Antagonistic drugs such as painkillers become less effective with repeated use since there is either an:
  1. Increase in sensitivity of receptors
  2. Increase in number of receptors

Mode of action of recreational drugs

Recreational drugs
Higher Human Biology
Unit 3 Notes
The cells of the nervous system and neurotransmitters

• Many recreational drugs can mimic the action of neurotransmitters and will affect the transmission of nerve impulses in the reward circuit of the brain.

• Recreational drugs can stimulate the release of neurotransmitters, acts as agonists or antagonists and inhibit their reuptake or enzyme degradation.

• Recreational drugs therefore alter a person’s neurochemistry and so can lead to changes in:

  • mood
  • *e.g. happier/more confident/more aggressive*
  • cognition
  • *person becomes poorer at mental tasks such as problem solving and decision making*
  • perception
  • *misinterpretation of environmental stimuli e.g. colours, sounds, sense of time*
  • behaviour
  • *person is able to stay awake for longer and talk about themselves endlessly*

**Drug addiction/tolerance**

• Drug addiction is a chronic disease. The sufferer will compulsively seek out and use a drug regardless of the consequences.

• The initial use of the drug is often voluntary but the changes which occur after use soon override a person’s control.
Drug tolerance occurs when a person’s reaction to an addictive drug decreases in intensity although the concentration is the same. A large dose is then required to bring about the original effect.

**Sensitisation**

- Sensitisation is an increase in the number and sensitivity of neurotransmitter receptors.
- This occurs as a result of exposure to drugs which are antagonists, which block receptors; the body then responds by increasing the number of these receptors.
- Sensitisation leads to addiction.

**Desensitisation**

- Desensitisation is a decrease in the number and sensitivity of neurotransmitter receptors.
- This occurs as a result of exposure to drugs which are agonists, which stimulate receptors and cause feelings of euphoria.
- The body responds to this overstimulation by decreasing the number of these receptors and so a larger dose is required to bring about the original effect.
- Desensitisation leads to drug tolerance.

**Summary of ways in which recreational drugs can affect the synapse**

1) Stimulate or block neurotransmitter release.

2) Imitate neurotransmitter action (agonists).

Or
The cells of the nervous system and neurotransmitters

Block neurotransmitter binding / receptor sites (antagonists).

3) Inhibit neurotransmitter uptake.

Or

Inhibit neurotransmitter degradation