Module:
Biological Foundations of Mental Health

Week 3
Synaptic transmission & neurotransmitter systems

Topic 1
Action potentials and synaptic transmission – part 2 of 5

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Lecture transcript

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So in the last section, we discussed how the neurons are able to set up their resting membrane potential. Now in this section, now that they have established a resting membrane potential, we're going to look at how they can integrate signals from, for example, a presynaptic neuron, on the left here, and how that would integrate the response to the postsynaptic neuron. Now of course, here we're going to discuss a one-to-one relationship. But it's important to realise that these neurons can receive multiple inputs somewhere in the region of up to 400 presynaptic inputs to a neuron. So you can see the diversity of the response here.

Now, this signal, if we think about the anatomy of a neuron, is largely integrated via the dendrites and the cell body, as you can see here. So these signals are responding by the dendrites and the cell body, and then they travel through the cell body, making their way towards the axon initial segment, which we'll discuss in relation to the generation of an action potential.

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So how is this signal transmitted? What is this signal? Well, it's known as a graded potential, and if you remember from the previous talk, we spoke about how these ion channels in the membrane can flux specific ions, in this case, sodium, as you can see here on the left. Now, this presynaptic neuron has caused the opening of a ligand-gated channel on the postsynaptic cell. When this is opened, sodium has fluxed in, causing a positive change. And it's this change in potential of the membrane around the ion channel that's known as our graded potential.

And this can be both positive or negative. So for example, potassium and sodium ions are positively charged. So they will depolarise the postsynaptic cell, and that is, they will move it towards the triggering threshold for an action potential. Whereas chloride ions, being negatively charged, if they were fluxed, would move the resting membrane potential away from the triggering threshold and would result in an inhibition of the likelihood of firing.

Now, these graded potentials are best described by the analogy of dropping a stone into water, and you see there's a diffusion of the wave in all directions. Now that's what happens with this charge. It diffuses in all directions. But as it does so, it rapidly decays. So therefore, one or two inputs to a cell will rapidly decay and not have an effect on the cell itself. We need the summation of different effects to get over this quickly diminishing response that we see in graded potentials.

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Slide 5

Now, to actually result in the triggering of an action potential, as we mentioned, the presynaptic neuron here on the left has to respond. This will result, for example, in neurotransmitter release. This neurotransmitter release will activate a graded potential on the postsynaptic neuron, and the arrows here denote the size of this graded potential.

As this graded potential moves through the cell body, it diminishes rapidly, as we mentioned, this electrotonic transmission. It reaches then, at the start of the axon, this region called the axon initial segment, here denoted as AIS, and as it reaches that axon initial segment, there's a threshold, in this case, minus 55 millivolts.

Now, this threshold is the triggering point above which the all or nothing event of an action potential will be initiated. If this graded potential, such as on the left here, reaches the axon initial segment and it's below this threshold, then no action potential is generated. The graded potential decays, and the cell returns to its resting membrane state. However, if this graded potential is just above or succeeds the, in this case, minus 55 millivolt triggering potential, then we get this rapid flux of sodium ions in this very robust depolarisation and hyperpolarisation phase that we will discuss in the next lecture, known as the action potential.

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Now, as I mentioned, any single response is likely, or won't be enough, to trigger this response, so there are a couple of ways by which the postsynaptic neuron can integrate signals from multiple responses.
The first one is known as spatial summation, and that is where, in this case here, if a single channel was to respond, that graded potential may not be above the threshold and would not reach the AIS and trigger an action potential.

However, if, for example three inputs-- I'm only using three in this case, but we mentioned before, there can be up to 400-- three inputs were to fire simultaneously, their responses would be summed in the cell body. So now in the red here, you can see we have a much larger graded potential, which can travel to the axon initial segment above the threshold for triggering, and generate the action potential. So this is spatial summation. This is based on the localisation of inputs around the dendrites and the cell body.

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The other method is temporal summation, and this is based on the timing of triggering, either by a single presynaptic input or by multiple inputs. And in this case, if a single action potential was to fire and it wasn't appropriate, that wouldn't happen. And then a second one fires, and you can see that both of these graded potentials don't pass the threshold, so no action potential is generated.

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However, if the first and second graded potentials and postsynaptic neuron were to fire quickly, causing this graded potential in the cell body, these responses would be summed. As you can see on the right, they would sum on top of each other and potentially allow the triggering of an action potential. So by this mechanism, both the spatial localisation of inputs firing and the temporal, that is the speed, of the firing, and the speed in relation to one another, can significantly impact the action potential propagation.

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Now, the postsynaptic cell responds in a multitude of ways. We have what we call excitatory postsynaptic potentials, and these are those potential changes that happen in response to the positively charged ions, such as sodium and potassium. They will move the membrane potential towards the triggering threshold for an action potential - and here it would be depicted here in green.

But we also have inhibitory postsynaptic potentials, and if you remember, I mentioned chloride ions. Because these are negatively charged, if chloride ions flux into the postsynaptic cell, they will move the resting membrane potential towards a hyperpolarised state, that as, more negative, and further away from this triggering threshold, which we had at minus 55 millivolts.

So if the green neuron here was to fire, and we record, using a glass electrode down here, the response of the postsynaptic cell, we see this excitatory postsynaptic potential in green. But if the red neuron is to fire, we see this inhibitory postsynaptic potential. So the resting membrane potential is moved away from the triggering threshold, and as you can see in both cases, this decays relatively quickly.

Now, the postsynaptic cell, as we mentioned, has somewhere in the region of about 400 inputs. So you could imagine that the response is dependent upon the integration of these multitude of signals, both positive and negative. In this case, for example, if the green and the red neuron, fluxing, causing the opening of channels fluxing in sodium and chloride ions, for example, were to fire, what the end result for the postsynaptic neuron, of course, is a balance of both this positive and negative charge. So, we can fine-tune the membrane potential and the likelihood for triggering of the postsynaptic neuron.