Chapter 8

Sensory Discrimination and Integration

1. General sensorimotor principles

The fundamental question that we ask in this book is: how does a nervous system turn sensory information into appropriate motor behaviour? The answer to this question is the ultimate goal of neuroscience. Yet, as we have seen in the previous chapters, the answer is not simple. Even the most elementary behaviours require the coordinated activity of many neurons, and the function of each neuron depends on the activity of many others. Thus, we cannot hope to understand the function of a single neuron in isolation. Instead, we must study the properties of whole populations of neurons and the way they interact with each other.

This approach is not new. Indeed, it is the reason why we have chosen to begin this book with a discussion of the properties of single neurons. Nevertheless, it is only recently that we have begun to be able to study the activity of large populations of neurons in behaving animals. Thanks to the development of multi-electrode recording techniques and of powerful computers, we are now starting to understand how the activity of many neurons is combined to produce behaviour. In this chapter, we will look at how sensory information is represented by the activity of large populations of neurons. We will then see how this information can be used to guide behaviour. Finally, we will look at how sensory information from different modalities is integrated to produce a unified perception of the world.

2. Sensory discrimination

In the previous chapters, we have seen that the activity of sensory neurons is correlated with the presence of specific stimuli in the environment. For example, we have seen that the activity of neurons in the primary visual cortex is correlated with the presence of edges of a particular orientation in the visual field. Similarly, we have seen that the activity of neurons in the auditory cortex is correlated with the presence of sounds of a particular frequency. These correlations between neural activity and stimulus properties are the basis of our ability to perceive the world around us.

However, these correlations are not perfect. A given neuron will respond to a range of stimuli, not just to one specific stimulus. Moreover, the response of a neuron to a given stimulus is not always the same. It varies from trial to trial, even when the stimulus is presented under identical conditions. This variability in the response of neurons is one of the main reasons why it is difficult to understand how the brain works.

The variability in the response of neurons is not entirely random. Much of it can be explained by the fact that neurons are not isolated from each other. They are connected to each other by synapses, and the activity of one neuron can influence the activity of many others. This means that the response of a neuron to a given stimulus depends not only on the stimulus itself, but also on the activity of the neurons that are connected to it.

Another source of variability is the fact that neurons are not perfect detectors. They are subject to noise, which can arise from a variety of sources, including the random opening and closing of ion channels in the membrane. This noise can make it difficult to detect small changes in the activity of a neuron.

Despite these sources of variability, it is possible to extract a great deal of information about the stimulus from the activity of a population of neurons. This is because the variability in the response of different neurons is often correlated. That is, if one neuron responds more than usual to a given stimulus, other neurons that are connected to it are likely to do the same. By taking advantage of these correlations, it is possible to reduce the effects of noise and to obtain a more reliable estimate of the stimulus.

3. The trigeminal nuclei

In order to illustrate the principles that we have discussed so far, we will now look at the trigeminal nuclei. The trigeminal nuclei are a group of brainstem nuclei that receive sensory information from the face and mouth. They are involved in a variety of functions, including the control of chewing, swallowing, and facial expression. They also play an important role in the perception of pain and temperature from the face.

The trigeminal nuclei are divided into three main parts: the principal nucleus, the spinal nucleus, and the mesencephalic nucleus. The principal nucleus is located in the pons, and it receives input from mechanoreceptors in the face and mouth. The spinal nucleus extends from the pons down into the upper cervical spinal cord, and it receives input from nociceptors and thermoreceptors in the face and mouth. The mesencephalic nucleus is located in the midbrain, and it receives input from proprioceptors in the muscles of mastication.

The trigeminal nuclei project to a number of different targets, including the thalamus, the cerebellum, and the motor nuclei of the brainstem. The projections to the thalamus are organized somatotopically, with different parts of the face and mouth represented in different regions of the thalamus. This somatotopic organization is also found in the primary somatosensory cortex, which receives input from the thalamus.

The trigeminal nuclei are also connected to each other by a number of interneurons. These interneurons allow the different nuclei to communicate with each other and to coordinate their activity. For example, the principal nucleus and the spinal nucleus are connected by interneurons that allow them to share information about the location and intensity of stimuli.

The trigeminal nuclei are also subject to modulation by descending inputs from higher brain centers. These inputs can enhance or suppress the activity of neurons in the trigeminal nuclei, depending on the behavioral context. For example, the activity of neurons in the trigeminal nuclei is enhanced during chewing, which helps to ensure that we are aware of the food in our mouth.

4. Coding of contact location

One of the most important functions of the trigeminal nuclei is to encode the location of contact between the face and objects in the environment. This is essential for a number of behaviors, including exploration, feeding, and grooming. The trigeminal nuclei use a variety of mechanisms to encode contact location, including the activity of individual neurons, the pattern of activity across populations of neurons, and the timing of neural activity.

The activity of individual neurons can encode contact location because each neuron has a receptive field, which is the region of the face or mouth where a stimulus can activate the neuron. The receptive fields of neurons in the trigeminal nuclei are organized somatotopically, so that neighboring neurons have receptive fields that are located in neighboring regions of the face or mouth. This means that the location of a stimulus can be determined by the activity of the neuron that is activated by the stimulus.

The pattern of activity across populations of neurons can also encode contact location. When a stimulus contacts the face or mouth, it activates a group of neurons with overlapping receptive fields. The pattern of activity across this group of neurons can be used to determine the location of the stimulus. For example, if a stimulus activates neurons A, B, and C, but not neurons D, E, and F, then the stimulus is likely to be located in the region of the face or mouth that is covered by the receptive fields of neurons A, B, and C.

The timing of neural activity can also encode contact location. When a stimulus contacts the face or mouth, it activates neurons in the trigeminal nuclei with a certain latency. The latency of the response depends on the distance between the location of the stimulus and the receptive field of the neuron. Neurons that are activated by stimuli that are close to the receptive field have short latencies, while neurons that are activated by stimuli that are far from the receptive field have long latencies. By measuring the latency of the response of a population of neurons, it is possible to determine the location of the stimulus.

5. Coding of contact force

In addition to encoding contact location, the trigeminal nuclei also encode the force of contact between the face and objects in the environment. This is important for a number of behaviors, including chewing, swallowing, and facial expression. The trigeminal nuclei use a variety of mechanisms to encode contact force, including the activity of individual neurons and the pattern of activity across populations of neurons.

The activity of individual neurons can encode contact force because the firing rate of a neuron is related to the force of the stimulus that activates it. Neurons that are activated by strong stimuli have high firing rates, while neurons that are activated by weak stimuli have low firing rates. By measuring the firing rate of a neuron, it is possible to determine the force of the stimulus that activates it.

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6. Coding of contact velocity

The trigeminal nuclei also encode the velocity of contact between the face and objects in the environment. This is important for a number of behaviors, including chewing, swallowing, and facial expression. The trigeminal nuclei use a variety of mechanisms to encode contact velocity, including the activity of individual neurons and the pattern of activity across populations of neurons.

The activity of individual neurons can encode contact velocity because the firing rate of a neuron is related to the velocity of the stimulus that activates it. Neurons that are activated by fast stimuli have high firing rates, while neurons that are activated by slow stimuli have low firing rates. By measuring the firing rate of a neuron, it is possible to determine the velocity of the stimulus that activates it.

The pattern of activity across populations of neurons can also encode contact velocity. When a stimulus contacts the face or mouth, it activates a group of neurons with overlapping receptive fields. The pattern of activity across this group of neurons can be used to determine the velocity of the stimulus. For example, if a stimulus activates neurons A, B, and C in that order, then the stimulus is likely to be moving in a certain direction. If a stimulus activates neurons C, B, and A in that order, then the stimulus is likely to be moving in the opposite direction.

7. Coding of contact texture

The trigeminal nuclei also encode the texture of objects that we touch. This is important for a number of behaviors, including exploration, feeding, and grooming. The trigeminal nuclei use a variety of mechanisms to encode contact texture, including the activity of individual neurons and the pattern of activity across populations of neurons.

The activity of individual neurons can encode contact texture because the firing rate of a neuron is related to the texture of the stimulus that activates it. Neurons that are activated by rough stimuli have high firing rates, while neurons that are activated by smooth stimuli have low firing rates. By measuring the firing rate of a neuron, it is possible to determine the texture of the stimulus that activates it.

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The activity of individual neurons can encode object size because each neuron has a receptive field, which is the region of the face or mouth where a stimulus can activate the neuron. The receptive fields of neurons in the trigeminal nuclei are organized somatotopically, so that neighboring neurons have receptive fields that are located in neighboring regions of the face or mouth. This means that the size of a stimulus can be determined by the activity of the neurons that are activated by the stimulus.

The pattern of activity across populations of neurons can also encode object size. When a stimulus contacts the face or mouth, it activates a group of neurons with overlapping receptive fields. The pattern of activity across this group of neurons can be used to determine the size of the stimulus. For example, if a stimulus activates neurons A, B, and C, but not neurons D, E, and F, then the stimulus is likely to be a large stimulus. If a stimulus activates neurons A and B, but not neurons C, D, E, and F, then the stimulus is likely to be a small stimulus.

28. Coding of object identity

The trigeminal nuclei also encode the identity of objects that we touch. This is important for a number of behaviors, including exploration, feeding, and grooming. The trigeminal nuclei use a variety of mechanisms to encode object identity, including the activity of individual neurons and the pattern of activity across populations of neurons.

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29. Coding of object location

The trigeminal nuclei also encode the location of objects that we touch. This is important for a number of behaviors, including exploration, feeding, and grooming. The trigeminal nuclei use a variety of mechanisms to encode object location, including the activity of individual neurons and the pattern of activity across populations of neurons.

The activity of individual neurons can encode object location because each neuron has a receptive field, which is the region of the face or mouth where a stimulus can activate the neuron. The receptive fields of neurons in the trigeminal nuclei are organized somatotopically, so that neighboring neurons have receptive fields that are located in neighboring regions of the face or mouth. This means that the location of a stimulus can be determined by the activity of the neurons that are activated by the stimulus.

The pattern of activity across populations of neurons can also encode object location. When a stimulus contacts the face or mouth, it activates a group of neurons with overlapping receptive fields. The pattern of activity across this group of neurons can be used to determine the location of the stimulus. For example, if a stimulus activates neurons A, B, and C, but not neurons D, E, and F, then the stimulus is likely to be located in the region of the face or mouth that is covered by the receptive fields of neurons A, B, and C. If a stimulus activates neurons D, E, and F, but not neurons A, B, and C, then the stimulus is likely to be located in a different region of the face or mouth.

30. Coding of object movement

The trigeminal nuclei also encode the movement of objects that we touch. This is important for a number of behaviors, including exploration, feeding, and grooming. The trigeminal nuclei use a variety of mechanisms to encode object movement, including the activity of individual neurons and the pattern of activity across populations of neurons.

The activity of individual neurons can encode object movement because each neuron has a receptive field, which is the region of the face or mouth where a stimulus can activate the neuron. The receptive fields of neurons in the trigeminal nuclei are organized somatotopically, so that neighboring neurons have receptive fields that are located in neighboring regions of the face or mouth. This means that the movement of a stimulus can be determined by the activity of the neurons that are activated by the stimulus.

The pattern of activity across populations of neurons can also encode object movement. When a stimulus contacts the face or mouth, it activates a group of neurons with overlapping receptive fields. The pattern of activity across this group of neurons can be used to determine the movement of the stimulus. For example, if a stimulus activates neurons A, B, and C in that order, then the stimulus is likely to be moving in a certain direction. If a stimulus activates neurons C, B, and A in that order, then the stimulus is likely to be moving in the opposite direction.

31. Coding of object texture

The trigeminal nuclei also encode the texture of objects that we touch. This is important for a number of behaviors, including exploration, feeding, and grooming. The trigeminal nuclei use a variety of mechanisms to encode object texture, including the activity of individual neurons and the pattern of activity across populations of neurons.

The activity of individual neurons can encode object texture because each neuron has a receptive field, which is the region of the face or mouth where a stimulus can activate the neuron. The receptive fields of neurons in the trigeminal nuclei are organized somatotopically, so that neighboring neurons have receptive fields that are located in neighboring regions of the face or mouth. This means that the texture of a stimulus can be determined by the activity of the neurons that are activated by the stimulus.

The pattern of activity across populations of neurons can also encode object texture. When a stimulus contacts the face or mouth, it activates a group of neurons with overlapping receptive fields. The pattern of activity across this group of neurons can be used to determine the texture of the stimulus. For example, if a stimulus activates neurons A, B, and C, but not neurons D, E, and F, then the stimulus is likely to be a rough stimulus. If a stimulus activates neurons A and B, but not neurons C, D, E, and F, then the stimulus is likely to be a smooth stimulus.

32. Coding of object shape

The trigeminal nuclei also encode the shape of objects that we touch. This is important for a number of behaviors, including exploration, feeding, and grooming. The trigeminal nuclei use a variety of mechanisms to encode object shape, including the activity of individual neurons and the pattern of activity across populations of neurons.

The activity of individual neurons can encode object shape because each neuron has a receptive field, which is the region of the face or mouth where a stimulus can activate the neuron. The receptive fields of neurons in the trigeminal nuclei are organized somatotopically, so that neighboring neurons have receptive fields that are located in neighboring regions of the face or mouth. This means that the shape of a stimulus can be determined by the activity of the neurons that are activated by the stimulus.

The pattern of activity across populations of neurons can also encode object shape. When a stimulus contacts the face or mouth, it activates a group of neurons with overlapping receptive fields. The pattern of activity across this group of neurons can be used to determine the shape of the stimulus. For example, if a stimulus activates neurons A, B, and C in that order, then the stimulus is likely to be moving in a certain direction. If a stimulus activates neurons C, B, and A in that order, then the stimulus is likely to be moving in the opposite direction.

33. Coding of object size

The trigeminal nuclei also encode the size of objects that we touch. This is important for a number of behaviors, including exploration, feeding, and grooming. The trigeminal nuclei use a variety of mechanisms to encode object size, including the activity of individual neurons and the pattern of activity across populations of neurons.

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34. Coding of object identity

The trigeminal nuclei also encode the identity of objects that we touch. This is important for a number of behaviors, including exploration, feeding, and grooming. The trigeminal nuclei use a variety of mechanisms to encode object identity, including the activity of individual neurons and the pattern of activity across populations of neurons.

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35. Coding of object