BLOCK 3

BRAIN LATERALIZATION

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UNIT 5 HEMISPHERIC SPECIALIZATION*

Structure

5.0 LEARNING OBJECTIVES

After reading this Unit, you will be able to:

- explain the concept of brain lateralisation;
- differentiate between left and right hemispheres;
- appreciate the role of the corpus callosum in our behaviour;
- know the importance of split-brain studies in understanding cognitive functions; and
- identify various methods to study hemispheric lateralisation.

5.1 INTRODUCTION

In previous block, we introduced the central nervous system and the peripheral nervous system. In this unit, we will be discussing the role of two hemispheres of the brain and their respective functions. We will also look into the ways to study the functioning of these hemispheres. You must be aware that majority of the people in

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the world are right handed (*dextrals*) but there are few people who are left-handed (*sinestrals*) and there is also a tiny fraction of people who can use their both right and left hands simultaneously to do work (known as ambidextral). Have you ever given a thought why people differ in their handedness? The answer lies in the wiring of our hemispheres of the brain.

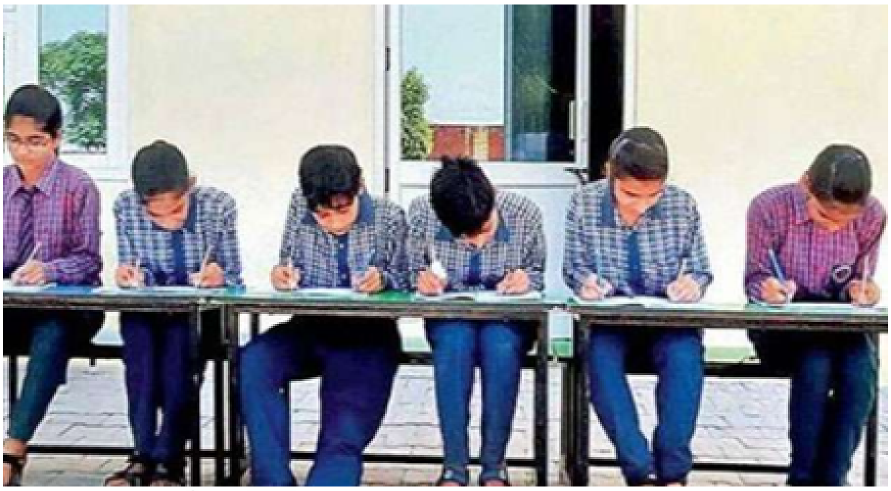

Figure 5.1: The ambidextral girls: These girls form Jind, Haryana, can write from both hands

Image Source: https://www.jagran.com

5.2 THE LEFT AND RIGHT HEMISPHERES

It is a general conception that a human being has one brain but anatomically our brain consists of two structures-left cerebral hemispheres and right cerebral hemispheres. These hemispheres have *contralateral* (opposite) connection with the rest of the body. That is, left hemisphere of the cerebral cortex is connected to the right side of the body while the right hemisphere is connected to the left side of the body. Due to this contralateral connection, our left hemisphere sees only the right side of the world while the right hemisphere sees only the left side of the world. But why this contralateral connection exists, no one knows. These hemispheres are separate from each other but they do exchange information through a number of channels. One of these channels is known as *corpus callosum*-a set of axons that connects left and right hemispheres. Other channels of communication between these two hemispheres include *anterior commissure*, the *hippocampal commissure*, *massa commissure*, *posterior commissure*, and *optic chiasm*. See Figure 5.2.

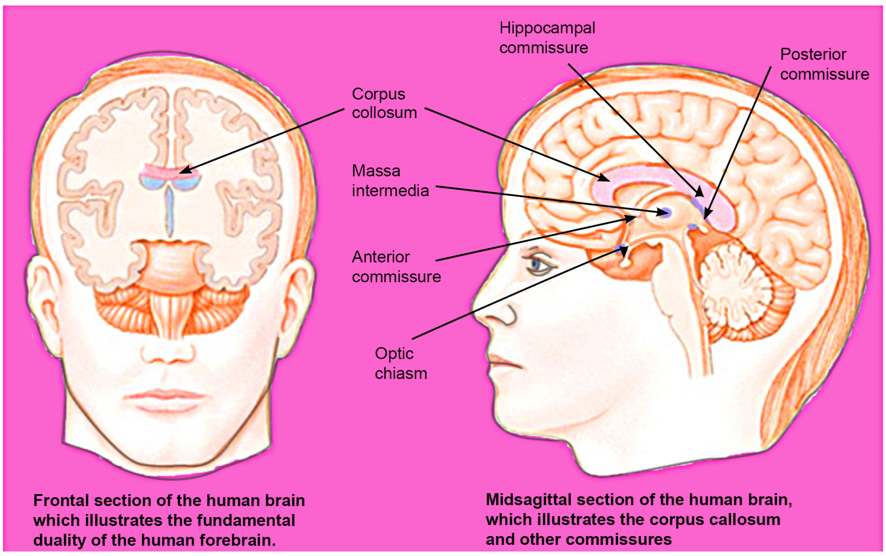

Figure 5.2: Illustration of the cerebral hemispheres and cerebral commissures

These hemispheres are similar in structure but not similar in functions. Left hemisphere possesses superiority in certain functions over the right hemisphere. Similarly, the right hemisphere is specialized over left in other cognitive functions. This difference in the specialization of function of hemispheres is known as *hemispheric specialization* or lateralization of function. However, this has not been the case in the past. Earlier, it was believed that our left hemisphere has a dominant role over right hemisphere in controlling and executing all important cognitive processes. This thinking led to the development of a theory known as cerebral dominance. As a result of this theory, left hemisphere was often termed as the **dominant hemisphere** while right hemisphere was called as the **minor hemisphere**.

Box 5.1: The Unknown Contributor of Cerebral Lateralization

"In 1836, Marc Dax, an unknown country doctor, presented a short report at a medical society meeting in France. It was his first and only scientific presentation. Dax was struck by the fact that of the 40 or so brain-damaged patients with speech problems whom he had seen during his career, not a single one had damage restricted to the right hemisphere. His report aroused little interest, and Dax died the following year unaware that he had anticipated one of the most important areas of modern neuropsychological research."

\- Pinel & Barnes (2017, p. 419)

5.2.1 What Led to the Development of the Theory of Cerebral Dominance?

Before moving further, it is important to discuss those events that led to the development of the theory of cerebral dominance. One can attribute the development of this theory (cerebral dominance) to two prominent names: Paul Broca (refer to Unit 3) and Hugo-Karl Liepmann. In 1864, a French physician, anatomist, and anthropologist, Paul Broca reported that all his aphasia patients had damage to the inferior prefrontal cortex of the left hemisphere (now this area is known as Broca' sarea). This made him conclude that left hemisphere is responsible for language ability. Similarly, Hugo-Karl Liepmann in the early 1900s reported that patients of apraxia also had damage on the left hemisphere. These major breakthroughs suggested that left hemisphere plays a key role in controlling language and voluntary motor activities and they laid the foundation of the theory of cerebral dominance.

Figure 5.3: Broca's area

Image Source: https://commons.wikimedia.org

Box 5.2 : Aphasia and Apraxia

Aphasia: Inability to produce or comprehend speech due to brain injury.

Apraxia: Inability to perform voluntary physical movement due to brain injury.

5.3 DIFFERENCE BETWEEN LEFT AND RIGHT HEMISPHERES

In the last section, we mentioned that left hemisphere possesses superiority in certain cognitive functions over the right hemisphere. Similarly, the right hemisphere is specialized over left in other cognitive functions. However, this "lateralization of function is statistical rather than absolute"(Pinel & Barnes 2017, pp. 428). It means that there is a relative functional difference between left and right hemispheres and one hemisphere possesses comparatively more specialization. Now, we will discuss those abilities that have been found to be lateralized. Take a look at Table 5.1. Lateralization of function has been presented briefly in seven major domains, namely, vision, audition, touch, movement, memory, language and spatial ability.

Table 5.1: Cerebral lateralization of functions

General Function	Left Hemisphere Dominance	Right Hemisphere Dominance
Vision	Words Letters	Faces Geometric patterns Emotional expression
Audition	Language sounds	Nonlanguage sounds Music
Touch		Tactile patterns Braille
Movement	Complex movement Ipsilateral movement	Movement in spatial patterns
Memory	Verbal memory Finding meaning in memories	Nonverbal memory Perceptual aspects of memories
Language	Speech Reading Writing Arithmetic	Emotional content
Spatial Ability		Mental rotation of shapes Geometry Direction Distance

Now, we will discuss some major examples of cerebral lateralization of functions.

1) *Language dominance*: This is the first ability for which cerebral lateralization was discovered. As already discussed in section 5.2.1, Paul Broca (1864) in his seminal work mentioned the correlation between left hemisphere and aphasia, suggesting a dominance of left hemisphere over right hemisphere in language ability.

2) *Ipsilateral movement* : Opposite of contralateral is ipsilateral. It means on the same side.It is a well-established fact that our hemispheres are contralaterally connected to our body parts, i.e., left hemisphere controls right part and right hemisphere controls left body part. However, in 1996, Haaland and Harrington first observed in their fMRI study that complex, cognitive movement performed by one hand led to usual contralateral activation along with ipsilateral activation of the hemisphere. Interestingly, this ipsilateral hemispheric activation was found to be greater in the left hemisphere in comparison to the right hemisphere. It means that any damage to left hemisphere will affect left-hand movements more in comparison to the effect of the damage of right hemisphere on right-hand movements.

3) *Spatial ability*: Levy (1969) found in her study that in the context of spatial abilities, our right hemisphere has superiority over the left hemisphere. Any damage to right hemisphere leads to the disorders of spatial perception such as direction, geometry or distance.

4) *Emotional ability*: Numerous studies have suggested that our right hemisphere is better in decoding emotional cues than the left hemisphere. In a recent study by Etcoff and his colleagues (2000), found that people with left hemisphere lesion were more accurate in reading gesture, facial expression and detecting lie than the normal population. This suggests that people with aphasia are better at detecting a liar because of their damaged left hemisphere, thus, they are free to use right hemisphere and make reliable judgments. Further, it has also been reported that damage to right hemisphere prevents an individual from comprehending people's emotional expressions including humor and sarcasm (Beeman & Chiarello, 1998).

5) *Musical ability*: Using dichotic listening task, Kimura (1964) reported that our right hemisphere is superior in musical ability. Many other studies on patients with damage in the right hemisphere, are consistent with the finding of Kimura i.e., right hemisphere lesion disrupts the musical ability of such patients.

6) *Differences in memory*: Studies have suggested that both of our hemispheres have memory ability. However, the types of memory in which these hemispheres specialize differ from each other. According to the findings of Kelley et al. (2002), our left hemisphere plays a major role in verbal memory hemispheres whereas, right hemisphere plays greater role non-verbal memory.

Check Your Progress 1

1) What do you mean by hemispheric specialization?

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2) Explain the theory of cerebral dominance.

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5.4 CUTTING THE CORPUS CALLOSUM: THE SPLIT BRAIN

What will happen if there is any damage to corpus callosum or if we cut it down for epilepsy surgery? Before 1950, corpus callosum was one of a great mystery for neuroscientists. Corpus callosum is made up of 200 million axons and located in the middle of the two hemispheres. Due to its enormous size and central position, scientists always believed that it has some major role to play. Yet, studies on several laboratory animals (monkeys, rats, and cats) and people with damaged corpus callosum did not suggest anything.

5.4.1 Myers and Sperry's Groundbreaking Experiment

However, this conception about corpus callosum changed in 1953, when Myers and Sperry conducted a groundbreaking experiment on cats. For their experiment, they took 4 groups of cats:

1) Cats with severed corpus callosum (control group)
2) Cats with severed optic chiasm (control group)
3) Cats with severed corpus callosum and optic chiasm both (key experimental group)
4) Cats with intact brain or no damage to their brain (control group)

Corpus callosum and optic chiasm are the only two routes by which visual information can travel from one hemisphere to another hemisphere. The researchers cut completely through them for their key experimental group. This experiment was conducted in two phases. In the first phase, all cats were trained for a lever-press pattern discrimination task with a patch on one eye. Cats of all groups, including key experimental group, learned this task without any difficulty. This suggests that single hemisphere can also learn any task independently and as rapidly as two hemispheres can learn together. In the second phase of the experiment, the patch was switched to cats' other eye and were again given the same discrimination task to perform. It was found that the switching of the patch to other eye had no effect on the performance of cats except for key experimental group. In fact, this transferring of the patch had a devastating effect on key experimental group cats. Their performance immediately dropped down and they had to relearn the task like a beginner. This result made Mayer and Sperry conclude that our hemispheres have the capability to act as separate brains and the role of the corpus callosum is to transfer information across hemispheres.

Figure 5.4: Visual training apparatus. The cat, placed in the darkened box, obtains a food reward by pushing on the correct one of two translucent patterns interchanged in doors at the end of the box. Inset shows enlargement of the cat wearing the eye patch devised by Myers. Made of rubber, it is simply turned inside out to cover the other eye.

Image Source: Sperry (1961)

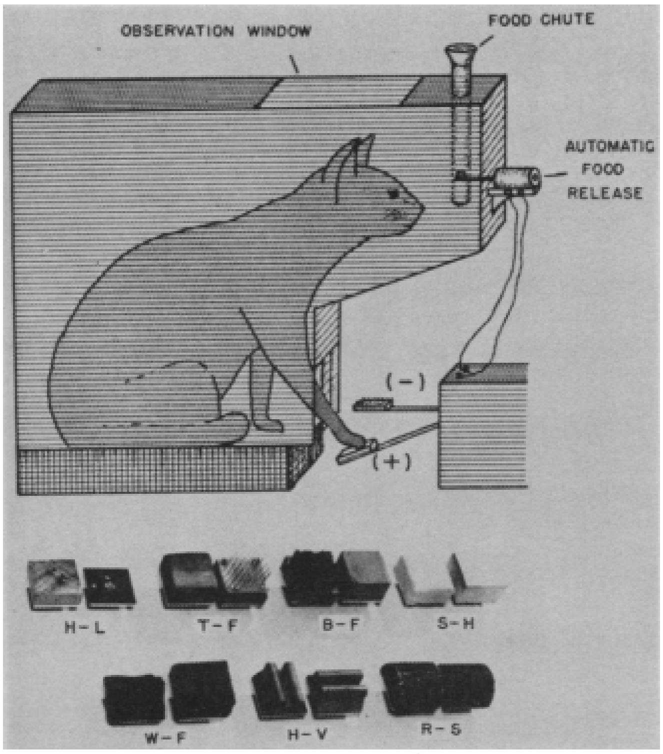

Figure 5.5: Simplified diagram of the pedal- pressing apparatus for training in tactile discrimination. Pairs of interchangeable pedal mountings are shown at bottom.

Image Source: Sperry (1961)

Based on this experiment, following two theoretical points may be concluded:

1) The role of the corpus callosum is to transmit information from one hemisphere to another.

2) If corpus callosum is completely cut down or damaged, each hemisphere can work independently as if they are carrying two separate brains in one skull.

Box 5.3: Development without a Corpus Callosum

What if someone does not have a corpus callosum since birth? How does it affect their behaviour? Studies have suggested that unlike those people whose corpus callosum was cut in later life, people born without any corpus callosum performed better at many tasks. According to research, the other commissures including anterior commissures compensate the absence of corpus callosum by becoming larger than usual.

5.4.2 Split-brain in Humans

In the last section, we discussed how severing the corpus callosum can affect the cat's behaviour. Now the question is, does severing of corpus callosum affect human behaviour? In order to treat critical cases of epilepsy, Vogel and Bogen started conducting commissurotomy- the operation of cutting through a band of muscle or nerve fibers (Merriam-Webster, 2018). These operations proved remarkably effective, as many epilepsy patients never experienced another major convulsion or epilepsy attack. People who have undergone such surgery are known as spilt-brain people. In order to understand the effect of this commissurotomy on human behaviour, Sperry and Gazzaniga conducted experiments on spilt-brain patients.

The basic premise of their methodology was similar to Sperry's previous experiment on laboratory cats: limiting information to one hemisphere only (Gazzaniga, 2005). Split-brain patients were asked to fix their gaze at the center of a display screen. A stimulus was presented on either left or right side of the screen just for 0.1 second.

This short duration of stimuli presentation was enough for perceiving it but not enough for patients to make any eye movement. Further, some fine tactual and motor activities were given to perform by each hand under a ledge. This procedure made sure that information about stimuli would not transmit to ipsilateral hemisphere. Their study concluded two findings:

- Just like laboratory animals, split-brain patients also have two independent hemispheres having their own consciousness, capabilities, and memories.
- Contrary to the hemispheres of laboratory animals, hemispheres of spilt-brain patients are not equal in their abilities.

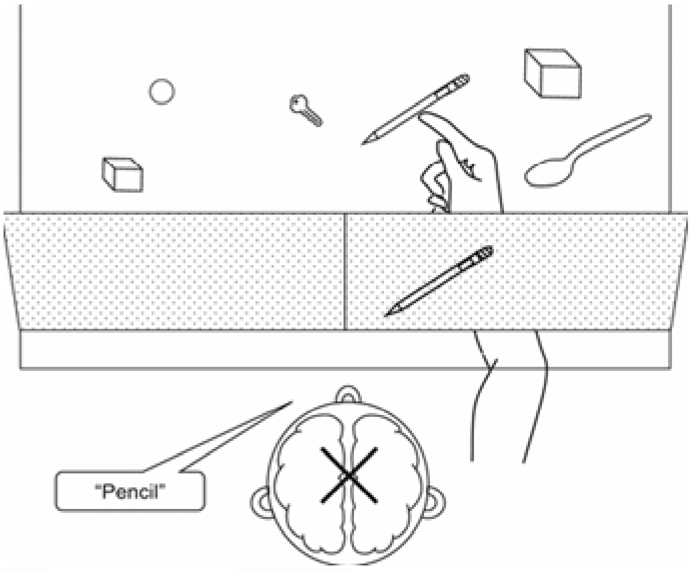

Figure 5.6: The testing procedure used to evaluate the neuropsychological status of split-brain patients

Image Source: Sevush (2016)

Box 5.4

Roger Sperry was awarded the Nobel Prize in Physiology in 1981 for the discovery of cerebral dominance. Sperry alongwith Michael Gazzaniga conducted the famous study on split brain which concluded that the brain has two sides that interprets and organizes information differently.

Now, we will discuss those evidence on the basis of which the researchers concluded the above two results i.e., hemispheres of split-brain patients can work independently and have unequal abilities.

1) In their study, Gazzaniga and Sperry presented either visual or tactual stimuli to either side of their hemispheres. When a picture of a spoon was presented on the right visual field or the spoon was placed in the patients' right hand, the left hemisphere gets activated and he or she does the following things:

   - the patient simply tells the name of the object i.e., spoon, or
   - picks out the correct object kept under the ledge with the right hand

   These two steps taken by patients indicate that their left hemisphere had received and stored the information. In the second phase of the study, a picture of the spoon was presented on the left visual field or the spoon itself was placed in the patients' left hand. This activates the right hemisphere, however, the responses given by patients were completely different.

- patients claimed that nothing appeared on the screen, or
- patients could not pick out the correct object kept under the ledge from their left hand
- patients claimed their unawareness about any object that has been placed in their left hand.

2) Cross-cueing/ cuing: According to Gazzaniga and Sperry (1967), hemispheres of spilt-brain patients were capable of communicating with each other through non-neural routes or external routes. They termed it "cross-cueing/cuing". Pinto et al., (2017) have defined the process of cross-cueing as "one hemisphere informing the other hemisphere with behavioral ticks, such as touching the left hand with the right hand". In their study, Gazzaniga and his colleagues presented red or green colour in the left visual field of the spilt-brain patients and asked them to name it after seeing it. They found that initially, their participants were not able to perform better than chance level (i.e., 50% correct response). However, gradually their performance improved dramatically. Initially, they believed that information is travelling between two hemispheres through some neural pathway. However, later they found that some external route such as head shakes or frowning inform left hemispheres of an incorrect answer.

3) Doing two things simultaneously: Gazzaniga (2005) in their studies found that each hemisphere of the split-brain patients can work independently. Interestingly, their efficiency in certain visual tasks was found to be better than healthy participants (Luck et al., 1989).

4) The Z lens: For split-brain patients, visual stimuli requiring more than 0.1 second to perceive could not be studied using the conventional method for restricting visual input to one hemisphere. To eliminate this barrier, Zaidel in 1975 developed the Z lens. It is a contact lens that is opaque on left side or right side. The Z lens limits the visual input to one hemisphere of the split-brain patients while they scan complex visual material for instance, pages of a book. Since the lens moves with the eye, it permits visual input to enter only one hemisphere, irrespective of eye movement.

Box 5.5: Evidence against two independent State of Consciousness

In 2017, in a paper, Dutch researchers Yair Pinto and his colleagues refuted the traditional view that split-brain patients carry separate consciousness. They proposed that severing of the corpus callosum can only split the visual perception but does not split consciousness i.e., like normal population, their brain also contains only one consciousness.

For more information on Pinto's idea and experiment, check the link below:

https://academic.oup.com/brain/article/140/5/1231/2951052
http://blogs.discovermagazine.com/neuroskeptic/2017/01/31/split-brain-consciousness/#.W9aoD9czbIV

Check Your Progress 2

1) What do you mean by split-brain?

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2) What are the major findings of Mayer and Sperry's experiment on cats?

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5.5 METHODS TO STUDY BRAIN LATERALISATION

About two centuries ago, *phrenology*, a pseudoscience, studied brain protrusion of the skull and associated it with a particular behavioural characteristic.Franz Joseph Gall and Johann Gaspar Spurzheim contributed to the system of phrenology. Based on observations of hundreds of human skulls, Gall proposed that there were twenty-seven skull protrusions on the scalp and each protrusion was related to a particular behavior. Phrenologists have assumed a one-to-one mapping between skull contour and behavior characteristic.

With the advancement in technology, human brain mapping is done by techniques like fMRI as well as combining other techniques, to identify the brain regions associated with actual mechanism that are basic to a cognitive process. There are broadly five methods to study cerebral lateralization namely, unilateral lesions, studies of split-brain patients, the sodium amytal test, the dichotic listening test and, functional brain imaging. Out of these five, we have already discussed the first two methods (see section 5.2 and 5.4). This section takes a look at the remaining three methods.

5.5.1 The Sodium Amytal Test

The sodium amytal test is also known as the Wada test (named after a neurologist, Juhn A. Wada) or intracarotid sodium amobarbital procedure (ISAP). This test is often performed prior to any neurosurgery, especially epilepsy surgery in order to determine which side of the hemisphere is responsible for language and memory functions. In a standard sodium amytal test, a small amount of sodium amytal or sodium amobarbital is injected into the right or left internal carotid artery. Sodium amytal works as anesthesia and for few minutes suspend the activity of that hemisphere on which injection is given. This allows neurosurgeons to assess the capabilities of other hemisphere using various procedures and tests.

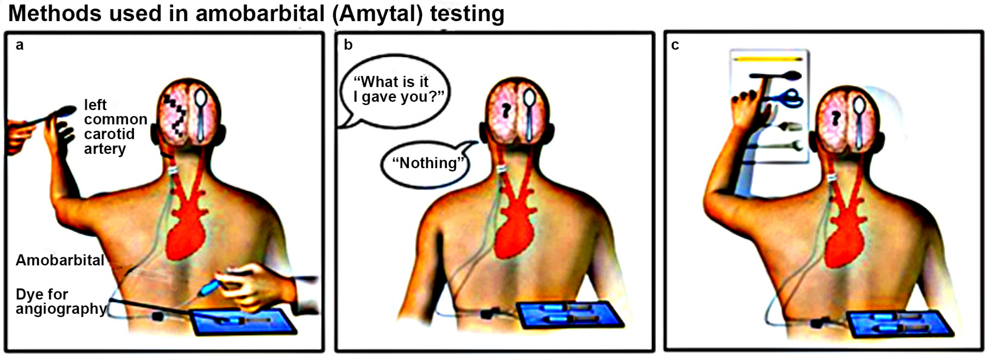

Figure 5.6: An illustration of the method used in Sodium amytal test

5.5.2 The Dichotic Listening Test

Initially, the dichotic listening test was used to investigate the phenomenon of selective attention. Since it is a non-invasive test, it is quite popular among neuroscientists for studying cerebral lateralization. In this method, using earphone, participants are presented with two different auditory stimuli to right and left ears simultaneously. Kimura (2011) simultaneously presented different pairs of digits in both ears of participants and asked to report all of the digits. He found that majority of the participants were able to reproduce digits correctly presented to their right ear than the left ear. Thus, suggesting that for the majority of participants their left-hemisphere was specialised for language.

5.5.3 Functional Brain Imaging

Brain imaging techniques offer researchers and neuroscientists to study the structure and functioning of our brain without operating it. There are many brain imaging techniques available such as fMRI, CT scan, PET scan, EEG, MEG etc. (for more on functional brain imaging techniques refer to Unit 1). Studies investigating cerebral lateralization have used fMRI and PET scan extensively. "While a volunteer engages in some activity, such as reading, the activity of the brain is monitored by positron emission tomography (PET) or functional magnetic resonance (fMRI)", (Pinel & Barnes, 2017, pg. 420).

Check Your Progress 3

1) List the main methods to study brain laterilization.

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5.6 SUMMARY

Now that we have come to the end of this unit, let us list all the major points that we have covered.

- Our hemispheres have contralateral (opposite) connection with the rest of the body. That is, left hemisphere of the cerebral cortex is connected to the right side of the body while the right hemisphere is connected to the left side of the body.

- Studies have suggested that left hemisphere possess superiority in certain functions over the right hemisphere. Similarly, the right hemisphere is specialized over left in other cognitive functions. This difference in the specialization of function of hemispheres is known as hemispheric specialization or lateralization of function.

- Paul Broca and Hugo-Karl Liepmann have played a major role in the development of the idea of cerebral lateralisation.

- In 1953, Myers and Sperry conducted a groundbreaking experiment on cats. Results of their experiment suggest that; (i) both of our hemispheres can act as separate brains and, (ii) the role of the corpus callosum is to transfer information across hemispheres.

- Sperry and Gazzaniga conducted many experiments on spilt-brain patients to understand the effect of commissurotomy on human behaviour.
- Five methods are used to study cerebral lateralization: unilateral lesions, studies of split-brain patients, the sodium amytal test, the dichotic listening test and, functional brain imaging.

5.7 KEY WORDS

Cerebral Dominance : It refers to an earlier conception that one hemisphere (often left) has a dominant role over right in controlling and executing all important cognitive processes.

Corpus Callosum : Composed of 200 million axons, it is the largest cerebral commissure. It is responsible for transferring learned information from one hemisphere to another.

Cerebral Lateralisation : It refers to the major functional difference between hemispheres of our brain.

Spilt-brain Patients : These are those patients whose corpus callosum is transacted surgically often for the treatment of epilepsy.

Cross-cuing/cueing : The process of "one hemisphere informing the other hemisphere with behavioral ticks, such as touching the left hand with the right hand" (Pinto et al. 2017).

Sodium Amytal Test : Also known as the Wada Test. This test is often performed prior to any neurosurgery, especially epilepsy surgery, in order to determine which side of the hemisphere is responsible for language and memory functions.

Dichotic Listening Test : It is a non-invasive test used for studying selective attention as well as cerebral lateralization. In this method, using earphone, with two different auditory stimuli are presented participant to right and left ears of the simultaneously.

5.8 REVIEW QUESTIONS

1) The major structure that connects the two hemispheres is called the:

   a) Genu

   b) Corpus callosum

   c) Anterior commissure

   d) Fornix

2) Research suggests that .... hemisphere is better in spatial abilities.

 a) Left hemisphere

 b) Right hemisphere

 c) Both hemispheres

3) The right hemisphere was used to know as

 a) Major hemisphere

 b) Dominant hemisphere

 c) Minor hemisphere

 d) Significant hemisphere

4) Difficulty performing movements when asked to perform them out of context (but can perform them when not thinking) is known as

 a) Aphasia

 b) Apraxia

 c) Sinestral

 d) Z-lens

5) Test for assessing language lateralization-injecting some anesthesia to one hemisphere prior to neurosurgery is known as

 a) Dichotic listening test

 b) Sodium amytal test

 c) Split-brain test

6) The organization of most functions of the brain is contralateral, meaning:

 a) Each hemisphere controls the opposite side of the body

 b) One hemisphere is more dominant than the other

 c) The right-hemisphere controls most functions

 d) The left-hemisphere controls most functions

7) What do you mean by brain lateralization? Explain.

8) What are the major differences between the left and right hemispheres? Explain with the help of their characteristics and functions.

9) Who are split-brain patients? How studying their behaviour helps in understanding cerebral lateralization?

10) Explain Mayer and Sperry's experiment on the cat and discuss how it helped in understanding brain lateralization?

11) What are the different methods to study brain lateralization?

5.9 REFERENCES AND FURTHER READING

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5.10 REFERENCES FOR FIGURE

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5.11 ONLINE RESOURCES

For more understanding on Split-brain, visit;

– https://www.nature.com/news/the-split-brain-a-tale-of-two-halves-1.10213

– https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6057762/

To learn more about brain lateralization, visit;

– https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3767540/

– https://dingo.sbs.arizona.edu/~tgb/pdfs/beverpdf_20.pdf

– http://www.psych.utoronto.ca/users/peterson/psy430s2001/Goldberg%20E%20Lateralization%20and%20novelty%20J%20Neuro%20Clin%20Neuro%201994% 20.pdf

Answers for Multiple Choice Questions

1) a, 2) b, 3) c, 4) b, 5) b 6) a