MECHANISMS OF LEARNING

SO WHAT IS LEARNING? AND HOW DOES IT HAPPEN?

Learning is any relatively permanent change in behaviour that occurs at the result of experience and is an ongoing process throughout the course of our lives. Learning can be active, such as making the effort to create cards of psychology terms with definitions and reciting those definitions, or passive, such as overhearing that a teacher is going to retire and then having that information at hand, even though you can’t recall who said it.

THE NATURE OF LEARNING

- It may occur deliberately or unintentionally.
- It may be immediate or delayed.
- It may be possible, but not evident or demonstrated.
- It is relatively permanent.
- It is ongoing, and occurs throughout our lives.

Learning is measured by performance under experimental conditions. It usually produces a learning curve.

THE LEARNING CURVE
Furthermore, the opposite can be true for the number of errors shown. The more you practise your tennis serve, the fewer errors you should make in your game:

![Graph showing the relationship between effort or time and the number of errors.](image)

### AREAS OF THE BRAIN INVOLVED IN LEARNING

The brain is a key structure in which most of the covert changes that occur due to learning are evident in an organism. Learning is a function of the nervous system. Memory is simply the representation of learning by neurochemical changes in brain structure at the molecular level. Many brain structures are active during the process of learning and all interact to enable learning to take place. It is important to understand that there is not one single area that is active during a particular type of learning, there are many simultaneously active. However, it is possible to identify certain areas of the brain that are predominantly active during certain types of learning. Learning involves experience that results in a change in performance, memory and emotional state. All these aspects are represented in particular areas and pathways in the brain that, in general, are different according to the type of task being learned.

Key structures of the brain involved in learning...

- Amygdala
- Hippocampus
- Cerebral Cortex
- Cerebellum
- Ventral Tegmental Area (VTA)
THE AMYGDALA

There is much evidence to associate the amygdala with emotion, and with learning about emotionally significant events. It is involved in a wide variety of emotional responses, including responding to linguistic threat, facial and vocal expressions of emotion, memory for emotional events, and even simple responding to pleasant and aversive stimuli, including music.

Damage to the Amygdala selectively impairs the formation or utilisation of mental representations of rewarding outcomes or goals. In its most extreme form, damage to the Amygdala may result in a person not being able to show any signs of fear nor recognise other aggressive or negative emotions in others.

The structure controls the learning and memory of pleasant and unpleasant emotional information. Role in emotional learning – specifically involved in learning to associate fear with a new unpleasant stimulus – this is essential for the organism’s survival. It is also highly involved in aggression. It strengthens the learning related to the hippocampus (declarative) by associating it with a positive or negative emotion. If this structure is damaged, then a person will not show any physical signs of fear.

THE HIPPOCAMPUS

Quite simply, this brain area allows us to learn declarative memories or learn from experience. In the Martin Luther King assassination example above, the hippocampus would have been activated in learning of the event and the Amygdala would have been activated in associating the event with positive or negative emotion. It is in this way that most brain areas involved in learning does not function independently of another but work in a systematic and integrated fashion to ensure learning takes place. The hippocampus is also involved in spatial learning and awareness (i.e. how to navigate you through space). For example, if you were staying over at a friend’s house and you needed to get up to go to the bathroom, you might wish to turn on the light to ensure you do not bump into any furniture. However, because your friend is asleep, you need to flick the light on and off very quickly to check the best way to exit the room. In the split second you do this, you are learning the best and most direct path to the door and in the dark; your spatial awareness would be tested as you try to exit. The hippocampus would likely be most active during this activity.

The hippocampus allows us to learn declarative memories or learn from experience. Involved in spatial learning and awareness (i.e. how to navigate through space).

Morris conducted a well known study in which he was able to demonstrate that spatial learning and awareness were related to the hippocampus. Lesions to the hippocampus impaired spatial learning.

Rats were placed in a “water maze” and would need to locate the invisible platform in the water so they would not have to continue swimming. Rats with no lesions to the hippocampus were able to locate the platform with ease, however, rats with lesions to the hippocampus showed little evidence of spatial learning or awareness and were unable to locate the platform or took numerous attempts to locate it.
THE SPECIFICS OF MORRIS’S EXPERIMENT

Materials:
- Pool of milky water with platform to stand on (just under the surface)
- 3 groups of rats

Participants: 3 groups of rats
- Group 1 – frontal lobe damage
- Group 2 – hippocampus damage
- Group 3 – no damage

Results display the importance of the hippocampus in allowing Long Term Potentiation (see page 22 for explanation):
- Group 3 – no damage – located platform more quickly each trial
- Group 1 – frontal lobe damage – performed about as well as group 3
- Group 2 – hippocampus damage – never got better, showed no evidence of learning

THE CEREBRAL CORTEX

Many parts of the cerebral cortex are involved with learning, however, the basal ganglia in particular is very active when learning the procedure of how to do something. The learning of procedural memories require the complex interaction of sensory and motor areas and sensory and motor processing to enable fluid movement. When learning how to tie up your shoelaces for the first time it was the basal ganglia that co-ordinated and integrated the information from these areas to allow you to correctly replicate this procedure. The basal ganglia particularly responsible for the learning of routine procedural memories, such as how to do up a tie for your school uniform. If damaged – a person may not be able to learn procedural memories.

Cerebral cortex: Many parts of this brain structure, in particular basal ganglia, are involved in learning and memory storage. Basal Ganglia is found in the cerebral cortex of the frontal lobe. It integrates sensory and motor information to enable smooth bodily movements; therefore, this area is associated with procedural memory. When the basal ganglia in this structure is damaged, people may be unable to learn procedural memories.
THE CEREBELLUM

There is considerable evidence that the cerebellum plays an essential role in some types of motor learning. The tasks where the cerebellum most clearly comes into play are those in which it is necessary to make fine adjustments to the way an action is performed. It is necessary to learn motor skills and works with the basal ganglia to co-ordinate movement sequences, posture, and muscle tone and muscle coordination.

Sometimes called the 'little brain'. It is necessary to learn motor skills and works with the basal ganglia to co-ordinate movement sequences. Helps coordinate voluntary movement and balance by regulating posture, muscle tone and muscle coordination by working with the basal ganglia in learning movement sequences.

THE VENTRAL TEGMENTAL AREA

The VTA is found in the midbrain and this area plays a vital role in Operant Conditioning as it processes the rewarding effects of reinforcement. In this way, it is particularly active when a person forms an addiction to a substance as they find the substance reinforcing in allowing them to experience what they feel is a positive consequence and enabling them to avoid the negative feeling of being without or withdrawing from the substance. It provides us with a nice feeling when we eat chocolate and therefore helps us learn to associate pleasant and unpleasant consequences with stimuli.

Found in the midbrain. It plays a role in the rewarding effects of reinforcement (operant conditioning), eg. provides the ‘nice feeling’ we get when we eat something yummy.

QUESTION 14

Sally has learnt to fear spiders because at the age of 7 she was bitten by a huntsman that was hiding inside her school shoe. Now, whenever she sees spiders, she screams and begins shaking.

In the learning of this classically conditioned emotional response, which brain areas would be most predominantly active? Explain your reasoning.
QUESTION 15
Peter is trying to teach his puppy Fido to sit. As Fido is very small and still a clumsy puppy, he is still struggling to learn how to sit without falling over. Peter gives Fido a schmacko for every time he sits, but the dog appears disinterested in this treat. Peter then gives Fido some bacon when he sits and Fido then learns that he will receive a pleasant outcome if he sits when Peter asks. Which areas would be involved in this type of learning? Explain your answer.
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_________________________________________________________________________
_________________________________________________________________________
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QUESTION 16
Briefly outline the role of the brain when learning takes place.
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_________________________________________________________________________
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THE NEURAL MECHANISMS AND PATHWAYS INVOLVED IN LEARNING

When we learn, many processes are occurring at a rapid rate without our conscious knowledge. Existing neural connections are firing at a greater rate, new connections are being created, old connections are being strengthened and damaged areas are resolving their issues by fixing severed connections or re-wiring old ones.
THE BASIC STRUCTURE OF A NEURON

NEURAL BASIS OF LEARNING

[Image of a neuron with labels such as dendrites, axon terminals, synaptic knob, myelin sheath, and synapse.]
A CLOSER LOOK AT NEURAL COMMUNICATION

NEURAL BASIS OF LEARNING

1. During learning, the axon terminals of the pre-synaptic (the sending) neuron release glutamate (a type of neurotransmitter) into the synaptic gap between the synaptic neuron and the dendrites of the neighbouring post-synaptic (the receiving) neuron. See animation:

   http://www.youtube.com/watch?feature=player_embedded&v=

2. This glutamate has an excitatory effect on the glutamate receptors, AMPA and NMDA in the post-synaptic neuron. An excitatory effect means that these receptors UNLOCK allowing the neurotransmitter, glutamate, to activate that neuron which makes it FIRE. It is this process that causes LONG LASTING changes at the synapse.

What do you mean by ‘long lasting changes’?

Long lasting changes mean that new growths on the pre-synaptic and post-synaptic neurons occur. This means that new connections are made to adjacent and adjoining circuits of neurons.

So what happens next?

3. The repeated glutamate stimulates the release of dopamine (another type of neurotransmitter) and it is THIS particular neurotransmitter that helps to generate new proteins.

   So dopamine interacts with the genes of the neuron to generate new proteins. Thinking in general terms, in might help to remember that proteins are building blocks. When we want to build muscle at the gym, we might increase our intake of protein. A similar process can occur at the neural level where more protein means that more neural connections can be built.

4. Dopamine interacts with the genes of a neuron to generate new proteins.

5. This prompts the growth of new filigree appendages on the pre-synaptic neurons and dendritic spines on the postsynaptic neuron.

6. This means that postsynaptic neurons are now more sensitive to future firing by other neighbouring neurons.
In summary:

Behaviour will cause the release of glutamate from the pre-synaptic neuron into the synapse. Glutamate travels across the synapse and binds to the appropriate receptor sites on the post synaptic neuron. The glutamate stimulates the growth of dendritic spines. This makes the postsynaptic neuron more receptive to future bursts of glutamate and results in long lasting structural changes to the glutamate receptors of the post synaptic neurons. Dopamine is also released which interacts with the genes in the neuron to generate new proteins in the neuron (allowing for the growth of spines and appendages).

This all leads to:

- Repeated firing of neural circuits.
- Resulting in LONG LASTING structural changes to the glutamate receptors of postsynaptic neurons.
- The greater likelihood of presynaptic and post synaptic neurons firing AT THE SAME TIME and this causes LONG TERM POTENTIATION.

**LONG TERM POTENTIATION**

*Refers to the long-lasting strengthening of the synaptic connections of neurons resulting in the enhanced or more effective functioning of the neurons, whenever they are activated.*

So, Long Term Potentiation results from these structural changes at the neural level. In the diagram below you can see changes at the synapse where the post-synaptic neuron is more sensitive to firing.

**HEBBIAN THEORY**

Learning results in the creation of cell assemblies or neural networks which is why the Hebb Rule is often associated with the rhyme: ‘neurons that fire together wire together.’ When a neurotransmitter is repeatedly sent across the synapse this can affect the strength of these connections. Neurons that do not fire together weaken their connections.
LONG TERM POTENTIATION AND NEURAL FORMATION IN BRAIN AREAS

<table>
<thead>
<tr>
<th>Implicit (procedural)</th>
<th>Short-Term Memory</th>
<th>Long-Term Memory</th>
<th>Brain Structures Involved</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temporary increased release of neurotransmitters from PRE-synaptic neuron.</td>
<td>Gene activated growth of new synaptic connections extending from the PRE-synaptic neuron.</td>
<td>Amygdala, Cerebellum, Reflex pathways (spinal cord, etc.)</td>
</tr>
<tr>
<td>Explicit (episodic &amp; semantic)</td>
<td>Temporary increase in the number of receptor sites in POST-synaptic neuron.</td>
<td>Gene activated growth of new synaptic connections extending from the POST-synaptic neuron.</td>
<td>Hippocampus, Temporal Lobe</td>
</tr>
</tbody>
</table>

Initially, NMPA receptors inhibit Glutamate transferring across, however, if enough AMPA receptors allow glutamate across, the NMDA becomes a secondary receiver and heaps of glutamate can cross over and effect the post synaptic dendrite. This leads to more AMPA receptors being made available which further increases the amount of glutamate that can cross over the synapse in proceeding action potentials. This change in structure leads to Long Term potentiation and eventually the creation of new synapses to keep up with demand and this leads to the creation of a Long Term Memory Formation!

Morris’s water maze experiment not only identified the role the hippocampus plays in spatial learning, but also helped us to understand how important NMDA receptors are to learning. For example rats treated with the NMDA receptor blocker APV perform poorly in the Morris water maze, suggesting that NMDA receptors play a role in learning. And since long-term potentiation (LTP) also requires NMDA receptors, spatial learning may require LTP.
DEVELOPMENTAL PLASTICITY AND
ADAPTIVE PLASTICITY OF THE BRAIN

CHANGES TO THE BRAIN IN RESPONSE TO LEARNING
AND EXPERIENCE; TIMING OF EXPERIENCES

PLASTICITY AND THE BRAIN

The basic structure of the Nervous System is set before birth; however, neurons are flexible living cells that can grow new connections. The ability of the brain to reorganise the way it works is referred to as plasticity.

Plasticity can be defined as the ability of the brain’s neural structure or function to be changed by experience throughout the lifespan.

There are two types:

- Developmental Plasticity
- Adaptive Plasticity

Neuroplasticity includes several different processes that take place throughout a lifetime. It does not consist of a single type of morphological change, but rather includes several different processes that occur throughout an individual's lifetime. Many types of brain cells are involved in neuroplasticity, including neurons, glia, and vascular cells.

Neuroplasticity has a clear age-dependent determinant. Although plasticity occurs over an individual’s lifetime, different types of plasticity dominate during certain periods of one’s life and are less prevalent during other periods.

The environment plays a key role in influencing plasticity. In addition to genetic factors, the brain is shaped by the characteristics of a person's environment and by the actions of that same person.

Neuroplasticity occurs in the brain under two primary conditions:

1. During normal brain development when the immature brain first begins to process sensory information through adulthood (developmental plasticity).

2. As an adaptive mechanism to compensate for lost function and/or to maximise remaining functions in the event of brain injury (adaptive plasticity).

DEVELOPMENTAL PLASTICITY

Developmental plasticity refers to changes in the brain’s neural structure in response to experience during its growth and development due to our own maturational blue print or plan. It is influenced by genes we inherit but is also subject to influence by experience.
SYNAPTOGENESIS IS THE PROCESS OF FORMING NEW SYNAPSES

Synaptogenesis can be broken down into two parts: synapto + genesis. The first part of the word refers to the term synapse, which was defined earlier in the site. Genesis, the second part of the word, means to create. Thus, synaptogenesis is the creation of new synapses. In addition to the construction of brand new synapses, synaptogenesis can also refer to the efficiency of a synapse.

Although synaptogenesis occurs throughout a healthy person’s lifespan, an explosion of synapse formation occurs during early brain development. Synaptogenesis is particularly important during an individual’s "critical period" of life, during which there is a certain degree of neuronal pruning due to competition for neural growth factors by neurons and synapses. Processes that are not used, or inhibited during this critical period will fail to develop normally later on in life.

SYNAPTIC PRUNING IS THE PROCESS OF ELIMINATING SYNAPTIC CONNECTIONS

Over the first few years of life, the brain grows rapidly. As each neuron matures, it sends out multiple branches (axons, which send information out, and dendrites, which take in information), increasing the number of synaptic contacts and laying the specific connections in the case of the brain, from neuron to neuron. At birth, each neuron in the cerebral cortex has approximately 2,500 synapses. By the time an infant is two or three years old, the number of synapses is approximately 15,000 synapses per neuron (Gopnick, et al., 1999). This amount is about twice that of the average adult brain. As we age, old connections are deleted through a process called synaptic pruning.

Synaptic pruning eliminates weaker synaptic contacts while stronger connections are kept and strengthened. Experience determines which connections will be strengthened and which will be pruned; connections that have been activated most frequently are preserved. Neurons must have a purpose to survive. Without a purpose, neurons die through a process called apoptosis in which neurons that do not receive or transmit information become damaged and die. Ineffective or weak connections are "pruned" in much the same way a gardener would prune a tree or bush, giving the plant the desired shape. It is plasticity that enables the process of developing and pruning connections, allowing the brain to adapt itself to its environment.
SENSITIVE OR CRITICAL PERIOD

The learning of another language is most easily acquired during a sensitive period in development and is more difficult and time consuming if undertaken outside this “window of opportunity”. An infamous case of language acquisition outside a critical period is in the case of “Genie” a young girl whose parents had locked her in a room with only a cot and potty for a good 13 years of her life. It would appear her parents did not attempt much communication with Genie and there was evidence to suggest she may have been beaten for making noise. As such, Genie learnt NOT to acquire language. The critical or sensitive period for language development is from birth up to about the age of 7-12 years. The window is said to gradually close from age 7. When Genie was found, a number of researchers attempted to help Genie learn how to communicate, and though she was able to acquire a fundamental vocabulary, it could never be anywhere near as complex, comprehensive and extensive as someone who acquired language normally throughout the early years of their life. For further evidence of this critical period, think about how difficult it is trying to acquire a second language in secondary school when compared to peers who have grown up in a bilingual household and can therefore speak two languages fluently!

ADAPTIVE PLASTICITY

This refers to changes occurring in the brain’s neural structure to enable adjustment to experience, to compensate for lost function and/or to maximise remaining functions in the event of brain damage.

**Re-routing** is when an undamaged neuron that has lost a connection with an active neuron may seek a new active neuron and connect with it instead.

**Sprouting** is the growth of axons or dendrites from a damaged neuron or from an intact neuron that projects to an area denervated by damage to other neurons. So sprouting is the growth of new bushier nerve fibres with more branches to make new connections. Thus, sprouting not only involves not only nerve growth, but re-routing as well.
SOME FAST FACTS ABOUT PLASTICITY!

- Sensory and motor cortices have very high level of plasticity.
- Not clear whether ALL brain areas have plasticity.
- A developing individual has greater plasticity.
- Infants recover more quickly from brain damage.
- The more complex the experience in terms of sensory input, the more distinctive the structural change in neural tissue.

USE OF IMAGING TECHNOLOGIES IN IDENTIFICATION OF LOCALISED CHANGES IN THE BRAIN DUE TO LEARNING SPECIFIC TASKS

PLASTICITY AND NEUROIMAGING STUDIES

How can we know that the brain changes? What evidence do we have of plasticity? Brain plasticity – the ability of the brain to adapt and reorganise neural pathways as a result of new experiences or learning – continues throughout life. The brain continues to adapt and form new pathways or alter existing pathways well into adulthood. There are many studies, both neuroimaging and post-mortem that would indicate the incredible, malleable nature of the brain. Advances in technology have enabled us to assess the brain before and after learning and document the changes that occur.

This is particularly encouraging news considering that reading deficits of children with developmental dyslexia persist into adolescence and adulthood. Increased right side brain activity of dyslexic children was also observed in regions not normally involved in phonological processing. These regions on the right side of the brain are mirror images of the normal areas in the left side of the brain responsible for processing language. This increase of activity may reflect a compensation effect such that the right side of the brain becomes involved to “compensate” for the left side. Before the intervention, the dyslexic children showed no evidence of brain activity specific to this task in these regions.
Adaptive plasticity need not always occur as a result of damage; neuroimaging studies have shown that musicians who require fine motor control of their left hand often have an overrepresented area on their right somatosensory cortex which is responsible for sensation of that left hand compared to non-musicians.

Furthermore, Licensed London taxi drivers who have the remarkable capacity to acquire and use knowledge of a large complex city to navigate within it show an increase in the volume of grey matter of the rear part of their hippocampus when compared to London Bus drivers, who only need to remember a few specific routes. While these gray matter differences could result from using and updating spatial representations, they might instead be influenced by factors such as self-motion, driving experience, and stress. However, London Cab drivers and bus drivers were matched using a matched participants design on their driving experience and levels of stress. The only difference between each pair was, of course, the nature of routes that they must travel on a day to day basis and the findings which showed a significant increase in gray matter volume in mid-posterior hippocampi.

Juggling has been shown to increase the volume of grey matter by as much as 3-4%! In a study of brain plasticity, one group of participants were taught how to juggle over a period of 3 months until they could juggle three tennis balls, without error, for at least 60 seconds and were compared to the control group who were not taught juggling. Both groups had MRI scans taken before and immediately after the study. The brain's of the jugglers evidenced the increase in brain matter. Interestingly, following the cessation of juggling, the brain's of the jugglers showed a decrease in the grey matter they had built up; at the very end of the study they had an increase of 3-4% of grey matter, but in the weeks after the study finished, the grey matter increase had reduced to just 1-2% demonstrating synaptic pruning.

Rosenzweig’s 1960’s experiment with rats used post-mortem studies to demonstrate the effects of experience of the brain. Rosenzweig focused specifically on the sensory experiences of rats. 25 day old rats were segregated into three groups, one standard condition in which the young rat was placed in a cage for 80 days with a couple of other rats; the impoverished condition, where a young rat was placed in a cage with no other rats for 80 days; and the enriched condition, in which a young rat was placed in a cage with a number of other rats and a wide variety of stimulus objects such as ladders, mirrors and exercise wheels. Obviously, the enriched condition exposed rats to a multitude of sensory experiences. When the brains of the rats were dissected, the cerebral cortex of the rats in the enriched condition were up to 10% heavier and had up to 20% more synaptic connections.