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HUMAN PERFORMANCE AND LIMITATIONS

CHAPTER 16 – INTEGRATION OF SENSORY INPUTS

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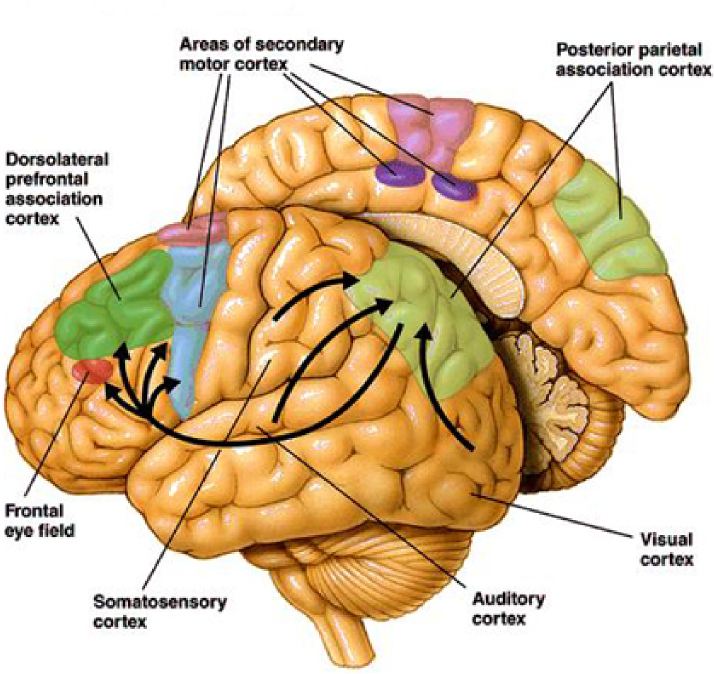
INTEGRATION OF SENSORY INPUTS

Introduction

A human has a visual cortex, an auditory cortex and a sensorimotor cortex, i.e. areas of the brain specifically devoted to particular senses. Each such cortex is composed of neural modules, which extract important mid-level and high-level features from low-level stimuli, in a way determined by the "laws of physics" of that domain.



The traditional five senses: Hearing, sight, smell, touch and taste

The visual cortex is the foundation of one of the seven senses. In addition to sight, sound, taste, smell and touch, there is proprioception (the nerves that tell us where our arms and legs are) and the Vestibular sense (the inner ear's inertial motion-detectors).

In the brain, the neural areas that are devoted solely to integrating and processing the senses account for a large part the human cortex. In order to examine the process whereby stimuli are transformed into recognisable information so that a decision can be made or action can be taken, we need to use a "sensory processing model" as it is impossible to relate each stage to distinct physiological structures in the brain.

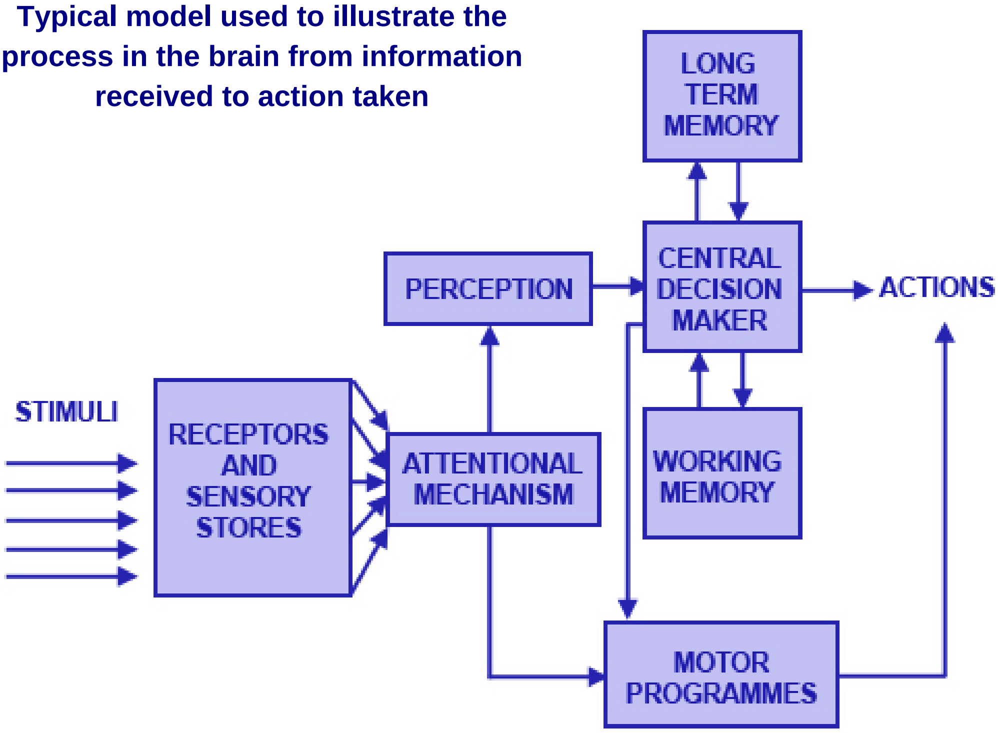
SENSORY PROCESSING MODEL

Sensory (or information) processing models enable us to determine how and where errors were made in certain situations, as well as to understand other factors such as stress that can influence human behaviour.

All processing models are based on the assumption that a series of stages, or mental operations, occur between information being received (or perceived) by the senses and responses being made.

Human factors have been identified as a contributing factor in 80% of aircraft accidents.

Typical model used to illustrate the process in the brain from information received to action taken



From sensory input to action takes time and the management of time is important to a pilot. The average time taken between stimulus and response to an unexpected event for which there is no rehearsed plan of action is about 5 to 6 seconds. This time can be reduced to between 0.2 - 2.0 seconds if the event is anticipated and/or there is a well-rehearsed plan of action to implement when it happens. This is one of the reasons why good training is important in aviation.

RECEPTORS AND SENSORY STORES

Physical stimuli in the form of sounds, visual patterns, etc. are received by the sensory receptors (e.g. the eyes and ears) and stored for a brief period after the input has terminated.

The key features of this system are:

- Information is physically represented, i.e. in the form of sounds or shapes.
- A separate store for each sensory system exists.
- The **input decays rapidly**.

> Rapidly Decaying Input
>
> - The information in the visual sensory store (also known as the **iconic memory**) lasts 0.5 - 1 second.
> - Information in the auditory sensory store (**echoic memory**) lasts between 4 and 8 seconds.

The importance of sensory memories is that it enables us to retain information for a brief period of time until we have sufficient spare capacity to deal with the new input.

ATTENTIONAL MECHANISM

Once the sensory organs have gathered the physical stimuli, they are passed on to the central decision maker for processing. During this processing stage, certain stimuli are recognised and stored by the attentional mechanism. This storing of stimuli is very important, especially if one is pre-occupied with the execution of a specific task and is not really paying attention to the surrounding stimuli.

Here are two examples where this system has to "grab" your attention through the "echoic" memory that is interrogated. (Remember, information in the auditory sensory store -echoic memory - typically lasts between two and eight seconds.)

Example 1: Time

It is possible to hear a clock chiming when you are for instance working on a computer, but you might only realize that you want to know the time after the second or third stroke. The echoic memory can now be "interrogated" or "replayed" to enable the strokes to be counted consciously.

Example 2: Radio Telephony

While you are flying you hear the radio-telephonic transmissions continuously. Sometimes you only realise that a message is for you when part of it has already been transmitted because you recognise the callsign through your attentional mechanism.

- The attention mechanism distinguishes useful from non-useful information.
- It makes the choice of subject for information processing.
- It involves some form of filtering (i.e. selective attention).
- Attention can be diverted.
- It can be divided (by switching).
- And it can be narrowed (particularly under stress).

SELECTIVE ATTENTION, OR THE 'COCKTAIL PARTY EFFECT'

This is a phenomenon where important, but unmonitored information is detected. You may have a lot of irrelevant traffic on the radio, none of which concerns you, so you don't pay much attention to it, but as soon as your call sign is transmitted, or you hear an instruction directed to another aircraft that may affect your operations, you are immediately attentive.

PERCEPTION

Perception involves the conversion of sensory information into meaningful structures (e.g. a pattern of sounds is recognised as a particular radiotelephonic message). This perception is not a complete representation of the information in the sensory store, but an immediate interpretation of it. This process is complex, as the physical information is coded using concepts (or descriptive labels) already existing in memory.

Example

A good example is when a person not previously exposed to an environment e.g. the radiotelephonic conversations in a control tower, is exposed to it. Because so much is happening that he "can't conceive", the person can hardly remember anything in a logical sequence or see a "pattern" behind the "chaos" in the transmissions.

Once a background or orientation has been given to that person, he has "hooks" where he can latch pieces of information onto - and the whole process can be perceived much more thoroughly and meaningfully.

It is thus true that we can "perceive" only what we can "conceive". The process is also influenced by the amount of processing capacity that the person is able to give the information being received. Since channel capacity is limited this way, much of the information that is "sensed" is lost without being "perceived".

Example: Lost Sensory Input

In the late sixties and early seventies during the Vietnam War, the Americans had so many systems in their aircraft to help them with communications, detection of enemy radars and so forth that the aircrew sometimes suffered from a "systems overload".

In some cases they had to monitor up to eleven different audio tones and frequencies, etc. and they started to block certain things out that distracted them. In one instance a pilot approached an airfield and did a wheels-up landing with the undercarriage warning horn blaring in his headset, the air traffic controller shouting at him to go around because he didn't have his wheels down and a red flare was fired from the tower to warn him not to land. His excuse that he gave to the board of inquiry was that he simply didn't hear the warning horn or the ATC and he didn't see a red flare either.

The purpose of our perceptual processes is to create an internal model of the outside world. This model is not only created by the information provided by our senses, but our experience and expectations also play a key role.

A good example is aircraft radio-telephonic conversations. To the layman it is notoriously incomprehensible, but the pilot is able to perceive it (generate a mental model) because:

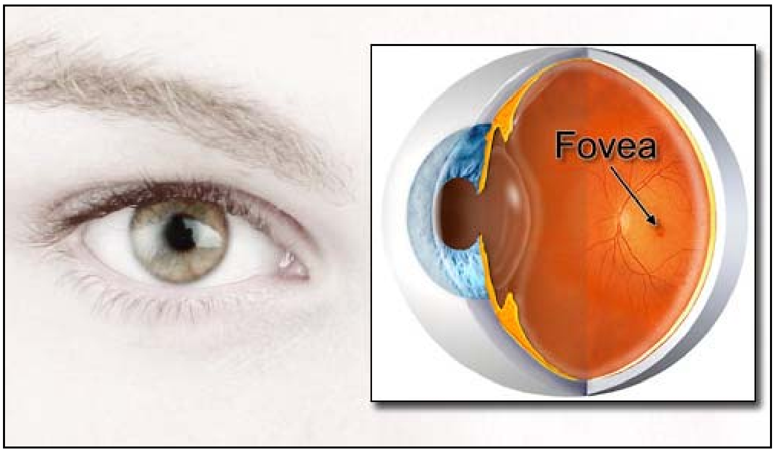
- He/she is experienced at dealing with the physical constraints and distortions of the auditory signal.
- More importantly, he/she has strong expectations with regards to the potential content of the information.

Example:

During a British civil aircraft movement, (with a mixed UK/US crew) into the USAF military airfield at Keflavik the QNH was heard as “986”. This was interpreted as 29,86in as the crew expected a QNH in inches and knew that the Americans clip leading numbers i.e. Freq. 119.75 is given as 19.75. At low altitude an alert radar operator asked for an altitude check against his mode C read out. Cross checking the QNH gave 986 Mb! (This confusion would have resulted in an altitude error of 750’ on the altimeter)

Note: The system does contain inherent dangers in that having developed a mental model, we will tend to seek information that will confirm the model and ignore other sources of input.

As mentioned before, our perceptual or mental model is based on both the information sensed by our receptors and on our expectations of the world. A good example of this is provided by the judgement of range or distance:



- One of the cues available to help us to perceive depth (build a three-dimensional model) is convergence. Convergence is the amount that the eyes have to converge in order to bring a visual target on to each fovea.

- Another cue is retinal size (objects become smaller on the retina with an increase in range).

This is of particular importance to the pilot, as it is used in every flight. An example is during the late stages of an approach for landing:

- During this stage the pilot is likely to judge the height above the ground from the retinal size of the runway.

- In order to use this information however, the pilot must have a stored knowledge or expectation of the likely size of the runway.

- If the runway is thus narrower than what is perceived, the height will be underestimated and round out may be too late.

This type of incident can happen very easily if you frequently take-off or operate out from a large and wide runway such as Sydney International or Adelaide International and suddenly you have to land at an airfield at a small town that is designed to cater for smaller aircraft such as Lexton (SA) or Parafield (SA).

CENTRAL DECISION MAKER (CDM)

Once information has been received, a decision must be made about what should be done with it. One of two likely actions could be:

To act or not to act

It may be used to initiate an immediate response, e.g. on hearing a warning sound (i.e. an enunciator's accompanying audio tone), the operator can switch the specific system off immediately, in which case the decision involves the selection of a response; or

To think about; to remember

Alternatively the operator may decide to hold the information in memory whilst a search is made for the problem that triggered the warning.

Information may be continuously entered and recalled from memory in order to contribute to the decision-making process.

At this point however a decision should be made to:

- Either retain the information for a short time in the working memory by actively rehearsing (or internally repeating) it; or

- Attempt to learn the information and to store it permanently in long-term memory, usually by imposing structure and form.

The brain is a single channel processor which to some degree limits our decision making capability. It cannot simultaneously process all the stimuli we might be receiving. **Multiple tasks will be handled either by:**

a) **Selective Attention**, where we process incoming stimuli to determine whether it is important to the task (e.g. disregarding ATC transmissions not preceded by our call sign) , or

b) **Divided attention**, where we alternatively allocate attention to competing, important tasks (watching both the runway and the ASI during an approach.)

NB! The speed of our mental processing decreases with age, but the accuracy improves with age.

WORKING MEMORY (SHORT TERM MEMORY)

Working memory is also sometimes referred to as short-term memory. This memory enables the information received, to be retained for a short period of time (normally between ten and twenty seconds) for example for the period between hearing a frequency on the radiotelephone and selecting it on radio unit.

Working memory is very robust and almost error free.

Verbal information is normally maintained in acoustic form. Errors in verbal working memory normally take the form of "acoustic confusions", i.e. "cat" may be recalled instead of "mat", and this is likely to occur even if the verbal material is presented in written form.

Spatial information on the other hand is normally stored in a visual code.

Information is maintained in the working memory through the process of rehearsal, with acoustic information being considered easier to retain than visual information because it is easier to rehearse sounds, than information in a visual form.

Unless rehearsed, inputs will be lost in **15 - 30 sec**.

The capacity of working memory is fairly limited in that the maximum number of unrelated items, that can be maintained when full attention is devoted to rehearsal, is about **7 (± 2)**.

Needless to say this has important implications on the design of checklists as well as to the amount of information that should be included in any single radiotelephonic message.

The process of clustering or "**chunking**" related material can expand the number of items retained in working memory.

Example of chunking
Each dot or dash can be heard as a piece of information that will occupy memory i.e. • • • can be heard as three dots. By listening for patterns we can make letters i.e. • • • can be interpreted as S and - - - can be heard as O.
We can go ever further, listening for the patterns of word i.e. • • • - - - • • • for SOS. In this example nine seemingly unrelated dots and dashes are chunked together to from one word, only one item to remember.

The information in working memory is lost by the process of interference, which causes the information to become confused by that, which was previously stored or replaced by the arrival of new information.

LONG-TERM MEMORY

The information retained in long-term memory can be classified into two types, **semantic memory** and **episodic memory**.

For an item to pass from short-term to long term memory, it must be *consolidated*. This is done by rehearsing (repetition or study) and it will later be improved by constant recall. This is a critical element in successfully studying a difficult subject.

A vivid occurrence may result in something being stored in long-term memory without rehearsal or study. Long-term memory **can be unreliable.** For example, irrespective of how much flying experience a pilot hay have, there is no guarantee that his memory will always be accurate.

Let's examine these two types of memory individually:

Semantic Memory (*words and general knowledge of the world*)

An interesting note is that most common amnesias affect the episodic but not the semantic memory. Shock and physical damage may well prevent recall of events, but are most unlikely to affect the store of basic knowledge of the world.

Most of our emotions and data processing ability (including memory) are situated in the temporal lobe. This includes the knowledge which we have that is associated with the things we are able to do, e.g. to understand a word or in the aviation environment to know the items on a checklist.

This memory is our memory for meaning. The organisation of the enormous amount of information, which we hold in semantic memory, is the object of great interest since it is known that our ability to use information presented to us on a computer's database that is organised in the same way as our semantic memory will be enhanced dramatically.

It is thought that once information has successfully entered our semantic memory, it is never lost. When we are unable to remember an item (e.g. a word), it is because we are unable to find where the item is stored in the memory system, not because the item has been wiped out of our memory.

Episodic Memory

This memory includes our knowledge about events, such as our memory of a particular flight or an incident on a flight deck.

One of the important features of episodic memory is that the information stored does not remain static but is heavily influenced by our expectations of what should have happened (according to our frame of reference that is...)

Our recollections from episodic memory are thus influenced by our expectations of the world in a similar way as our initial perceptions. This tendency to remember what "must have been" instead of what had been can be quite problematic in some instances.

Example:

A good example can often be found in eyewitness accounts of aircraft accidents.

Investigators of accidents have often found that eyewitnesses of aircraft accidents can mostly describe an accident that they saw in great detail. If ten witnesses from different backgrounds saw an accident they give ten different accounts, ranging from smoke, fire or debris flying off the plane before the accident or even strange noises being heard.

If video footage is available, quite often the video will show clearly that there was no smoke, fire, debris or noise.

MOTOR PROGRAMMES *(= SKILL)*

With many tasks that we execute, practice leads to a reduction in the amount of central processing required, and it may even lead to the execution of the task becoming automatic. For instance, in learning how to drive a car, the initially demanding task of changing gears can eventually be performed with little or no awareness.

This process of skill acquisition is often divided into three phases:

- **Phase One**

  In the first "cognitive" phase, the learner must think consciously about his/her actions and what he/she wants to do.

- **Phase Two**

  In the second "associative" phase, the separate components of the overall action become (with practice) integrated into a smooth operation.

- **Phase Three**

  In the third "automatic" phase, the action can be executed without conscious control. All that is normally required is an initial conscious decision to initiate the skill.

In skills such as driving a car, or flying an aeroplane, these behavioural sub-routines or "motor programmes" may not require continuous conscious control, but they do require conscious monitoring. It is easily possible to fly (using "motor programmes") and to maintain a radio conversation (using the "central decision maker") at the same time, but if the flying becomes difficult, the central decision maker has to be devoted to it - and the conversation will stop.

It thus appears that we can only do one thing that requires central processing at a time, while automated programmes or actions can run concurrently.

Unfortunately, although the advantage of the development of motor programmes is that they free our processing resources for other activities, they have the disadvantage of being open to particular types of errors. These errors, include action slip, reversion and environmental capture, tend to occur at the initial stage rather than at the execution stage of action.

Example:

A typical instance would be a very busy business executive that lifts up a ringing phone and shouts "Come in!"

Since actions controlled by motor programmes are performed without conscious awareness, considerable time can pass before the individual will realise that the behaviour was not as planned. The implications of these types of errors on the flight deck can obviously never be overestimated.

SITUATIONAL AWARENESS

All the foregoing has been concerned with ensuring that the pilot maintains accurate mental models of his/her environment (or that a situational awareness is maintained).

In order to ensure that a pilot maintains a good situational awareness, there are some guidelines that can be drawn from what was discussed previously:

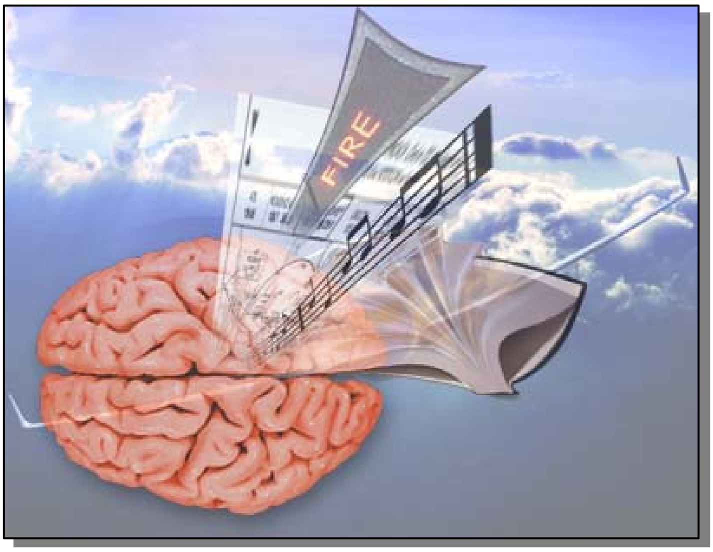
- **Gather Information** - Gather as much data as possible from every possible source, before making an inference (making up your mind).
- **Time** - Take as much time as is available to make your mind up (do not leap to conclusions). Remember that rapid decisions are seldom necessary.
- **Decide** - Consider all the possible interpretations of the data that you think of - including unlikely ones - before deciding which one suits the available data best.
- **Take Stock** - Once you have embarked on a course of action, try to stop occasionally to take stock of the situation.
- **Question** - Question whether your hypothesis still fits the data as events progress.
- **Test** - Consider ways in which you can test your actions to see whether your hypothesis is accurate.
- **Reconsider** - If incoming data does not appear to suit your hypothesis, do not assume the data is wrong or disregard it. Take time to reconsider the situation - retracing your steps to the first signs of the problem, if necessary.
- **Interpretation** - Make sure that you do not interpret the world in terms of how you would like it to be, but in terms of how it is. Always hope for the best - but plan for the worst.

RESPONSE

Our responses to stimuli will vary depending on the nature of the required action.

- Stimuli may invoke a decision that will result in an action. The action may be to do nothing.
- There is frequently a trade off between speed and accuracy – greater speed often results in less accuracy.
- With increased arousal, our response will be more rapid, but may be less accurate.
- Auditory stimuli (something we hear) are more likely to be misinterpreted.
- If we expected the stimuli our response will be faster (0.2 – 2.0 sec) and more accurate. If the stimulus was not expected, our response will be slower (5 – 6 sec)
- With increasing age up to about 60, our response will usually be slower, but more accurate.

IMPROVING MEMORY



Memory can be improved by:

- Rehearsing the action (Learn, practice).
- Organise (Arrange data into logical order).
- Imagery/Association. (With previously experiences)
- Mnemonics.
- Shorthand.

Some Aviation Examples

a) Your attention is caught by the sound of your call sign, or you hear another aircraft reporting at your position. Your *perception* is one of conflict, or danger. The *CDM* will then direct your response which may be to alert the other aircraft or to take evasive action.

b) If you hear another aircraft reporting an ETA the same as yours, you may decide to call him now (*CDM* involved) or store the information for later action.

c) When you start making radio calls as a student, you use your short-term memory and have to rehearse, (a very good idea) before pressing the button.

CATEGORIES OF BEHAVIOUR

The behaviour of pilots can be broken down into three categories:

SKILL BASED BEHAVIOUR

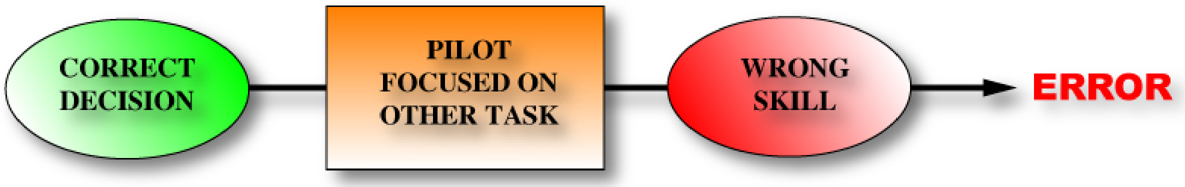
Skills may be acquired in different ways, either by breaking down and carefully studying the various elements of a skill (e.g. a golf swing), or by practicing the whole skill as a 'motor program'. They are often skills that are immediately translated into actions once the initial conscious decision to apply the skill is made.

Skill based behaviour can be summarised as follows:

- It is a behaviour that relies on the skills memory.
- Skills are usually stored as routines or motor programmes.
- They are carried out without conscious monitoring, but the decision to apply the skill must be initiated by the CDM
- We can do several routine tasks at the same time.
- They are often skills may be difficult to explain.
- Once learned, this type of skill may be difficult to modify.

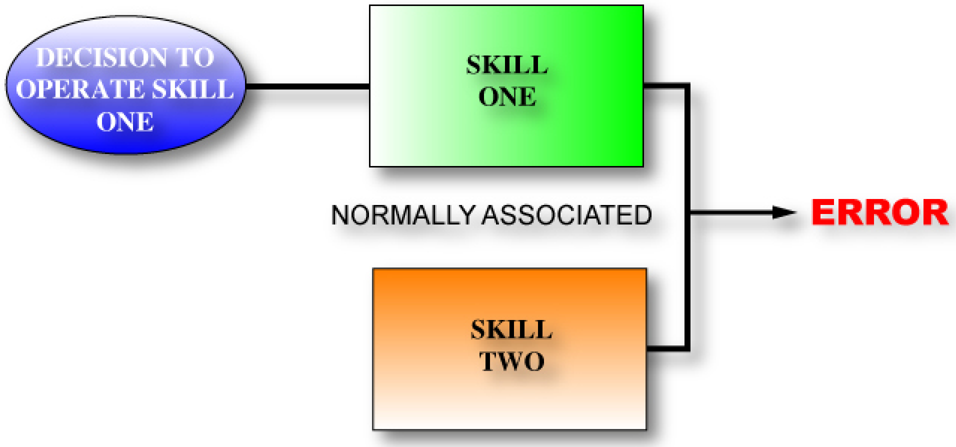
SKILL BASED BEHAVIOUR ERRORS

1. Action Slip



During a busy phase of flight such as just after take-off, the pilot may correctly elect to raise the undercarriage, but instead raises the flaps.

2. Environmental Capture



On the downwind leg, the instructor may instruct the student to carry out a flapless approach and landing. At the base turn point where flaps are usually lowered, the experienced student will automatically attempt to lower the flap.

3. Reversion

Many examples of this error occurred when there was little similarity in the cockpit layouts of various aircraft. Many pilots had difficulty moving to a new type, and would look for cockpit controls where they were located in their previous aircraft. Aircraft manufacturers now standardise cockpit layouts wherever possible to reduce the possibility of errors due to Reversion. (e.g. the cockpit layout of the Boeing 757 is almost identical to the B 767 – the only minor differences being in the overhead panel.)

Examples of Skill Based Behavioural Errors:

1. Action Slip

CRASH OF BEA TRIDENT AT STAINES

The aircraft was climbing out of London Heathrow bound for Brussels. Ninety seconds after takeoff, at the point where the flaps should have been retracted, the slat lever was selected up, causing the aircraft to approach a stall as the slats started to move. The aircraft entered a deep stall. The principal cause of the accident was the retraction of the leading-edge slats 60 knots below proper speed, precipitating the stall.

2. Environmental Capture

A student has been carrying out a session of circuits. The instructor says make this one a flapless, however when the student reaches the stage in the circuit where he would normally engage flap, he does so.

3. Reversion

A Viscount was being used for engine-out training at Mangalore. When the pilot under training began to run off the edge of the runway during take-off on only two engines, the check captain, taking over, pulled the aircraft into the air in an attempt to avoid any damage. The airspeed was too low to keep straight, and the aircraft was destroyed. The check captain had been flying a DC-4 earlier that day, and it was considered that he might have mistaken the Viscount's minimum control speed for that of the slower DC-4 speed.

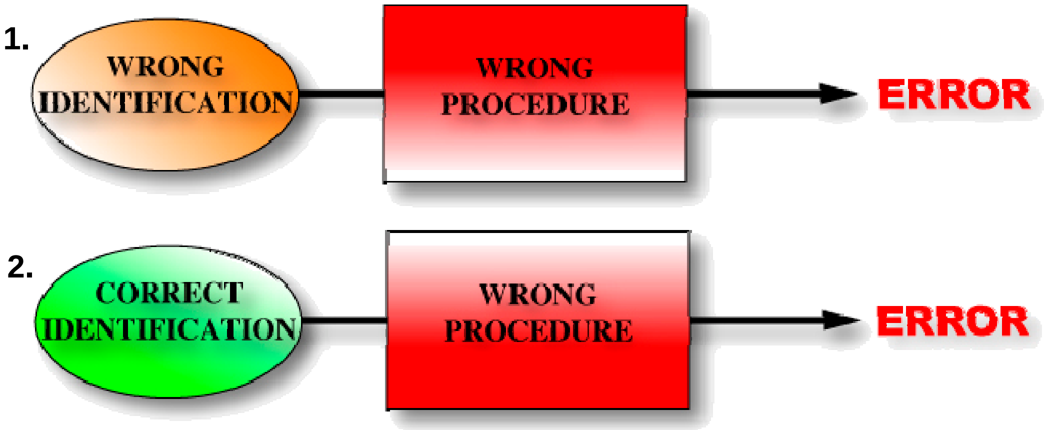
RULE BASED BEHAVIOUR

It is rule based behaviour that has made modern aviation as safe as it is today. Rule based behaviour is not stored as a motor program, but stored in our long-term memory as a set of rules to be followed. Cockpit and emergency procedures (e.g. forced landing procedures) are examples of this behaviour.

Rule based behaviour can be summarised as follows:

- It is behaviour stored in long term memory.
- The behaviour is learned as a **set of rules for action in predictable events**.
- Initiation of the action involves the central decision maker.
- In aviation, training in simulators is commonly used to establish behaviour (especially for emergencies training).
- Standardises and improves co-ordination between crew members.
- This behaviour can be very reliable.

RULE BASED BEHAVIOUR ERRORS



There are two common types of error. The first is when a wrong identification of the problem has been made and therefore a wrong procedure followed. (eg, misidentifying a stall warning for an over-speed warning and reducing rather than applying power.)

The second type of error is departure from the correct procedure. For example, failing to apply the correct Standard Operating Procedure of applying 'go-round' power when the ground proximity warning sounds.

Examples of Rule Based Behavioural Errors:

1. Wrong Identification

8 January 1989. East Midlands Airport, UK. The near-new British Midlands Airways B737-400, on autopilot, was climbing out of Heathrow. Passing FL283, severe vibration shook the aircraft and smoke appeared in the cockpit. The first officer commented that they had "got a fire", the captain took over, and glanced at the engine instruments. "It's the le... it's the right one," the first officer announced.

The serviceable engine was shut down and the descent was carried out with the failed engine operating (at idle power setting)

Wrong identification—wrong procedure

2. Correct Identification Incorrect Procedure

A very common example of this is when confronted by engine failure after take-off we are all trained to 'land ahead,' yet pilots still crash trying to turn back to the runway.

KNOWLEDGE BASED BEHAVIOUR

Knowledge based behaviour can also be termed 'decision making'. It arises not from motor programs or following rules, but will be a decision founded on clear thinking or reasoning and based often on knowledge derived from previous experiences.

- It requires information from memory and the environment.
- Actions and decisions are based on thinking and reasoning.
- Is a function of the Central Decision Maker.
- Is commonly called decision-making (discussed later).

An example would be a flight across the Indian Ocean from Dubai (UAE) to Perth, Western Australia. The aircraft suffers an engine failure. The Captain must decide whether to divert to Mumbai, Singapore, Djakarta, Darwin, Learmonth or carry on to Perth. Based on his knowledge and previous experiences, he must assess many variables such as time-to-destination, weather, suitability of the airport, accommodation for passengers, access to maintenance services, etc.

KNOWLEDGE BASED BEHAVIOUR ERRORS

Errors in this type of behaviour generally involve the following influences:

- Incoming data may be open to interpretation.
- Influences of expectation, experience, hopes and desires.
- Preference for 'comfortable' information.
- Unwillingness to test a formulated hypothesis.
- Unwillingness to accept conflicting data - which is called '**Confirmation Bias'**, or **'False Hypothesis'**

Examples of knowledge based behaviour errors:

1. The student pilot on a navigation exercise who reports over a fix because of the similarity of ground features to the ones he is expecting, ignoring the fact that time elapsed does not allow him to have reached the point.

2. The G.A pilot observes the oil pressure gauge reads zero. There is no supporting evidence from temperature gauges, etc. but the pilot carries out a forced landing