# Human Factors ZSHF

↳ for aviation engineers

↳ Humma Lai AV24a

## Introduction to Human Factors 1

The Human Factors Field:

↳ encompasses **all aspects** that can influence **human performance** and safety within **human-machine systems**

↳ includes: physical, cognitive and organizational factors

↳ How do human interact with technology and their environment?

↳ by studying: aim to improve system design to fit human capabilities, reducing errors, enhancing performance and increase safety

## Goal of Human Factors

↳ optimize the interaction between humans & systems / environment by considering human capabilities and limitations in design & operation

## Definition of Ergonomics – scientific discipline

↳ understanding of interactions among human & other elements of a system

↳ profession which applies theory, principles, data & methods → design → to optimize human well being and overall system performance

↳ ergonomists: contribute to the design and evaluation of tasks, jobs, products, environment and systems

to make them compatible with the needs, abilities and limitations of people

## History of Human Factors

**World War I:** selection, physiological problem (→ pilot (fatigue, hypoxia, stress))

↳ beginning of Human Factors as a discipline

↳ goal to understand how human body reacted to flying at higher altitudes and speeds

**World War II:** industrialization (machines become more complex)

↳ psychology: study human-machine interaction

↳ shift now: designing controls and displays that fit the human perception

**After World War II:**

↳ developed into a formal scientific discipline

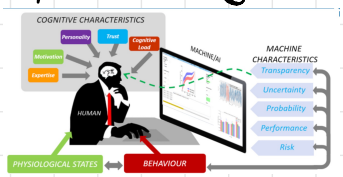


- Standardisation: of cockpit layouts (Basic-T instrument arrangement)
- Cabin pressurisation: solved physiological issues in jet aic
- Information displays: became more advanced & needed to adapt to new glass cockpit techno.

## Scope of HF & involved disciplines

↳ interdisciplinary field of applied research:

- cognitive, behavioural, experimental psychology
- physiology medicine
- engineering & systems design
- sociology



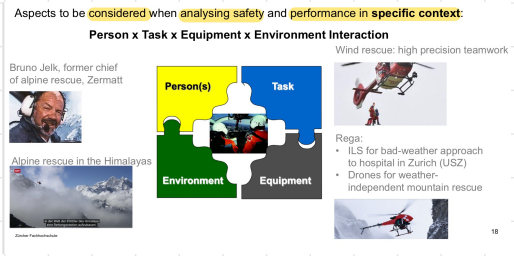

- Human factors and ergonomics is concerned with the **application of what we know about people** —their abilities, characteristics and limitations—**to the design of products** they use, **environments** in which they live **and work and jobs** they perform. Primary goals of the field of HF/E are **to reduce human error, increase productivity and enhance safety, comfort and enjoyment** for all people.
- The field is a **combination of numerous disciplines**, such as psychology, sociology, engineering, biomechanics, industrial design, physiology, anthropometry, interaction design, visual design, user experience and user interface design.
- Fields of employment in academic institutions, industry, military research institutions, consulting …
  - Human Factors Engineer: Professor
  - Ergonomist: Industrial designer
  - Usability Engineer: Human Factors consultant
  - Safety Scientist: Transportation safety specialist
  - Cognitive Systems Engineer: Human-Computer Interaction (HMI) specialist
  - UX Researcher: Research scientist

Person x Task x Equipment x Environment

# Application of HF — Humanizing Work

↳ making work safe, efficient & satisfying

- look how humans perform in a man-machine system
- make use of human capabilities in design
- enhance human excellence with tools
- avoid under- and overload situations on the job




# Sources for HF engineering

↳ standards & regulations → ICAO, EASA, BAZL

↳ models for human performance

- psycholog.: thought, action, feeling
- physiolog.: functioning of body & organs

# Need for HF → human performance affects system safety

causes of accidents

- designer: mechanism of A320
- manager: poor risk management
- operator: complicated maintenance
- regulator: delegation of responsibility

# Safety in Aviation

Definition: freedom from risk which is **NOT** tolerable

↳ risk is still present (→ acceptable residual risk)

↳ minimise risk to prevent harm

Hazard: potential for harm

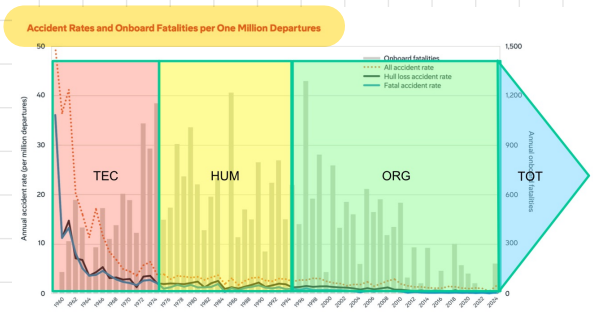
Risk: severity of harm × probability of the occurence harm

# Definition Aviation Accidents

↳ a/c damaged or destroyed → result of collision, fire, structural fail. or other event

example: pilot error, sabotage
adverse weather conditions

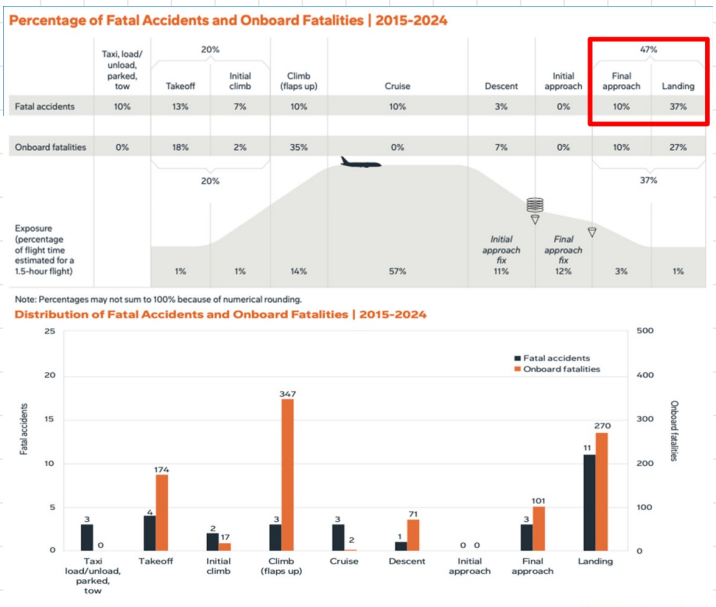
results in: fatalities, injuries and damage to property




**Unfallarten (Types of Fatalities)**

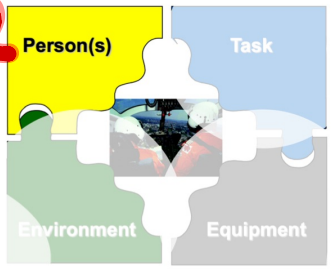
- ARC Abnormal Runway Contact
- CTOL Collision with Obstacle(s) During Takeoff & Landing
- CFIT Controlled Flight Into or Toward Terrain
- FUEL Fuel Related
- ICE Icing
- LOC-I Loss of Control - In flight
- MAC Midair/Near Midair Collision
- OTHR Other
- RAMP Ground Handling
- RE Runway Excursion (Takeoff or Landing)
- RI-VAP Runway Incursion – Vehicle, Aircraft or Person
- SCF-NP System/Component Failure or Malfunction (Non-Powerplant)
- SCF-PP System/Component Failure or Malfunction (Powerplant)
- UNK Unknown or Undetermined
- USOS Undershoot/Overshoot

interessant




Boeing (2025)

# Personality & Individual Differences 2




## Personality Concept

Goal: understand the concept of personality & how it is measured

## What Personality is

↳ corresponds to "... the unique, relatively enduring internal and external aspects of a person's character that influence behaviour in different situations."

(physical; psychol.; traits are stable over time)

- the state of being a person
- the characteristics and qualities that form a person's distinctive character
  - ↳ the sum total of all the physical, mental (↳ problem-solving, cognition, attention), emotional (↳ feelings) & social characterics (↳ teamwork, communication)
    - ↳ these characterics are enduring states of a person or momentary states (long-term stable; temporary emotions)

Trait vs. State:

| | Trait | State |
|---|---|---|
| Characterize … | **Enduring**, stable patterns of thinking, feeling, and behaving that persist over time and across situations | **Temporary**, situation-dependent expressions of thoughts, feelings, or behaviors |
| Reflect … | Baseline personality - who you are **in general** | Temporary fluctuations in personality - how you are **right now** (not overall) |
| Example domains: | | |
| - Extraversion | - Being shy and introvert | - Talkative and outgoing about favorite sports |
| - Anxiety | - Tendency to worry | - Feeling anxious about the result of the exam |
| - Mood | - Optimistic disposition (positive affect) | - Happy after the good result |
| - Agression | - Consistently responding to frustration or conflict with hostile thoughts, verbal hostility or physical agression | - Becoming very upset after being unfairly judged on an exam |
| - Confidence | - Feeling self-assured in most areas | - Feeling more confident after recent success |

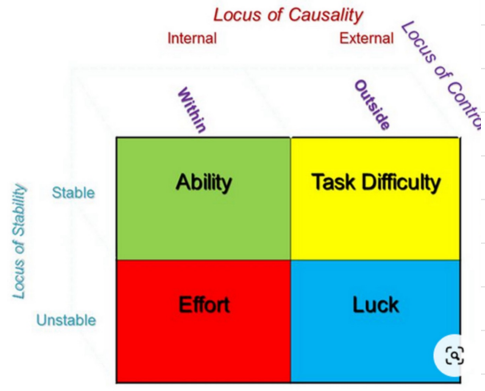
## "The Big Five" Personality Traits → OCEAN independet. validated in x studies

1. **O**penness to experience (inventive/curious vs. consistent/cautious)
2. **C**onscientiousness (efficient/organized vs. extravagant/careless)
3. **E**xtraversion (outgoing/energetic vs. solitary/reserved)
4. **A**greeableness (friendly/compassionate vs. critical/rational)
5. **N**euroticism (sensitive/nervous vs. resilient/confident)



# Locus of Personality → do you control what happens in your life or do you think outside forces control everything

With the help of the **Attribution Theory** understand how individuals explain causally in their head human behaviour.




**internal locus of control**: people think they can influence / change factors which are important for their success

**external locus of control**: people attribute outcomes to external forces
→ like luck
other thinks their own actions have little impact on what happens

## Core Self Evaluation

↳ stable part of personality
↳ how you subconsciously see yourself - deep fundamental belief not momentary feeling
  ↳ influences how you behave in situations

## 4 Dimensions:

- **Locus of Control**: my actions or fate?
- **Neuroticism**: how easily do you experience negative emotions? anger, stress, emotional instabil.
  high → fast
- **Self-efficacy**: confidence in your own ability
- **self-esteem**: overall sense of self-worth

## What determines Personality?

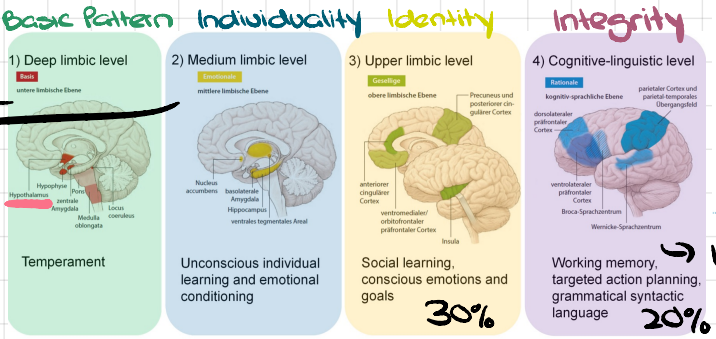
genes provide ingredients
environment works as shaping context

↳ heredity (genetics) influence 50% of personality

→ your biological make-up determines your personality

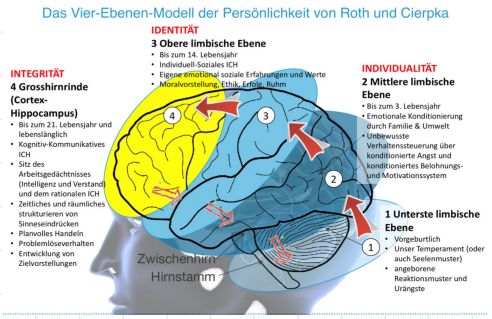
- physical characteristics: height, weight, skin
- social behaviour: naturally outgoing, calm, aggressive
- intellectual properties: learning-potential, problem-solving speed

# Development Stages for Personality




40% - 50% of personality (varying 20% - 70%)

↳ Hippocampus




1) develops before birth: **minimally influenced** by experience and education

What develops?

**temperament**: natural reaction to the world
↳ calm vs upset, sensitive vs. robust

**regulation of vegetative functions**, innate behav. (survival)
↳ sleep, hunger ↳ fear reaction

2) when develops? first months and years after birth

↳ not fully genetic or fully conscious

based on: **unconscious** **emotional conditioning**
↳ brain links experiences with basic emotions

example: when baby gets praised while exploring
→ curiosity = positive

- fear, happiness, sadness, hope ...

3) when: **late childhood** and **adolescence** by **social-emotional experience**
→ involves thinking, learning and social rules
↳ what success means, right or wrong, moral & ethics ambition, long-term goal, friendship, fame

→ attention control: to focus on what matters
→ social control: ability to regulate behaviour according to social rules

4) when: over the entire life-span → thinking, planning, language
↳ gives you the ability to **name your feelings**
→ I feel angry because...
↳ **thoughts are structured** & **put into order**
↳ reflects **how we want to see ourselves** and how **we want others to see us**
→ **self-image**, **personal values**, **long-term identity**

# Measuring Personality → FPI-R scales

## Challenges:

measuring personality with questionnaires is difficult:
personality is complex

12 personality dimensions:

1. Satisfaction with oneself (Lebenszufriedenheit)
2. Social orientation (soziale Orientierung)
3. Need for achievement (Leistungsorientierung)
4. Shyness (Gehemmtheit)
5. Irritability (Erregbarkeit)
6. Aggressiveness (Aggressivität)
7. Demandedness (Beanspruchung)
8. Physical troubles (körperliche Beschwerden)
9. Health sorrows (Gesundheitssorgen)
10. Openness (Offenheit)
11. Extraversion (Extraversion)
12. Emotionality (Emotionalität)

Friedrich, J., & M
*Handanweisung*

1. **completeness of the item pool**
item pool: list of questions that make-up a personality test
↳ challenge: items must cover all dimension of the personality

2. **validaton:**
- **Factor analysis** → checks whether items cluster the way they should
- **External criteria** → comparing test results with real-life behaviour or other validated tests

3. **norming**: personality test must be normed on large groups (>2000) representative samples

4. **methodological issues**
↳ social desirability: people tend to answer in a way that makes them look good
↳ self-concept: people may not see themselves accurately

# Motivation, Needs and Motives

Goal: understand the sources for motivation and the process of motivating

## Nature of Motivation

Motivation: willingness to behave → comes from drives and needs
↳ which activates goal directed behaviour

Need: state or experience of deficiency plus the desire to remedy it
↳ desire in biological / social / psychological

Motives: target classes and incentives one reacts to emotionally often arise from underlying needs

# Aspects of Motivation

Direction: What I am motivaveted/energized to do?

Intensity: How much energy to put in?

Endurance: How long and how persistent?

# Intrinsic vs. Extrinsic Motivation

Intrinsic: wish or intention to perform a certain action → because the action itself is considered exciting

advantage

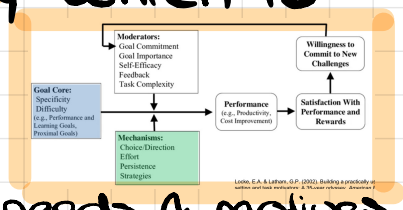
Extrinsic: action is performed because of reward or to avoid punishment

disatvantage

**Flow:** feeling of mental state of complete concentration in an activity which is experienced as pleasure

# Theories of Motivation




Content Theory: **What** motivates? basic needs & motives
↳ Pyramid of Needs

Process Theory: **How** motivation works? how we get active
↳ Goal setting Theory

# Attitude

Goal: to know how attitudes contribute to behaviour

## Attitude & Behaviour

↳ overall evaluation on something → object, person, idea
made-up of 3 parts:
emotions, behaviour, belief

**affective:** emotional reaction → How does it make you feel?

**behavioural:** what you tend to do because of your attitude? → How do you act?

**cognitive:** thinking, beliefs or opinions about the object → What do you believe to be true?

**Performance-Goal Orientation:**
Focus on demonstrating competence relative to others — the goal is to look competent and gain favorable judgments.

E.g., study maths to score highest in class or to avoid looking "dumb" in class.

- Belief in **giftedness, aptitude**
- Are competitive → win-lose

①

**Mastery/Learning-Goal Orientation:**
Focus on developing competence, improving skills, and understanding – the goal is personal growth and mastery of a task.

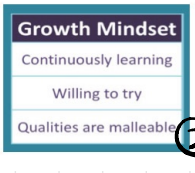
E.g., study math problems not just to get a good grade, but to deeply understand the concepts.

- Belief in **ability to learn, self-motivation**
- Cooperation/support → win-win

②




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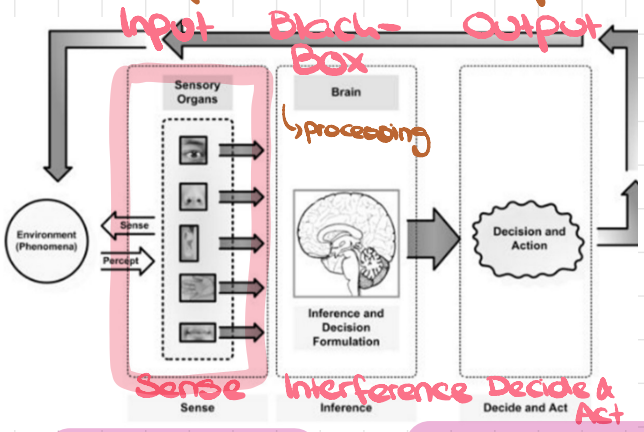

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# Information Processing: Biological Foundations & Senses 3

Goal: Know the biological foundations of human information processing – the nervous system and senses – and reflect them with respect to human-machine interface (HMI) design.

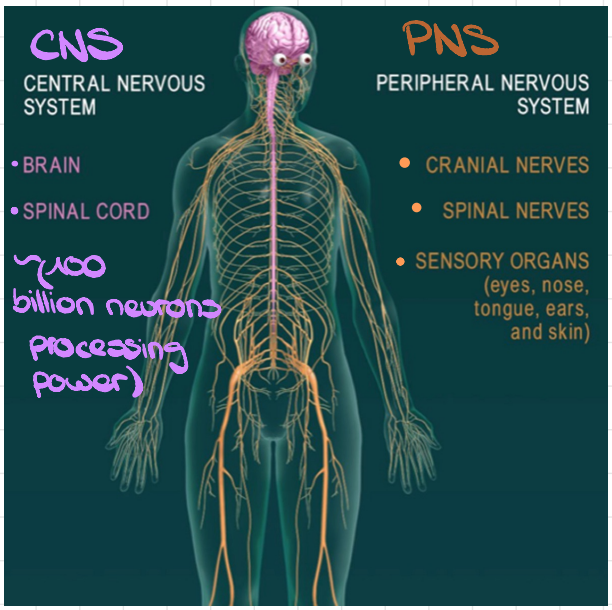


## Simplified Model of Human Information Processing




Goal: understand how info is transferred to and from the brain

## The Central Nervous System




CNS: processing power / computer

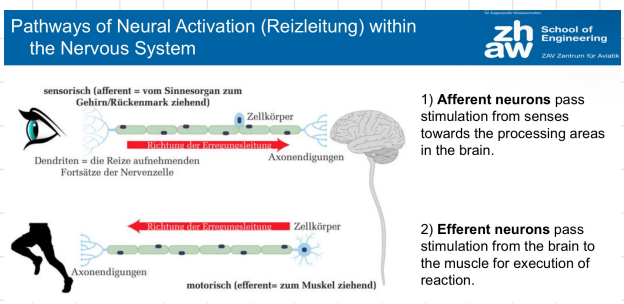
PNS: cables connecting sensors and muscles
→ transmits information to / from CNS

↳ messages travel through neurons as electrical signals

↳ afferent (arriving): going towards the CNS

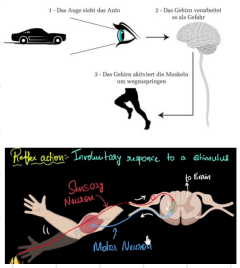
efferent (exiting): going away from the CNS

information input to → transmitted sensory organs through nerves → through the spinal cord & processed in the brain → reaction to the world are controlled by the brain for fine-tuned muscle movements




1) **Afferent neurons** pass stimulation from senses towards the processing areas in the brain.

2) **Efferent neurons** pass stimulation from the brain to the muscle for execution of reaction.




The nervous system works according to the principle of stimulus perception and (re-)action in two modes of operation: .

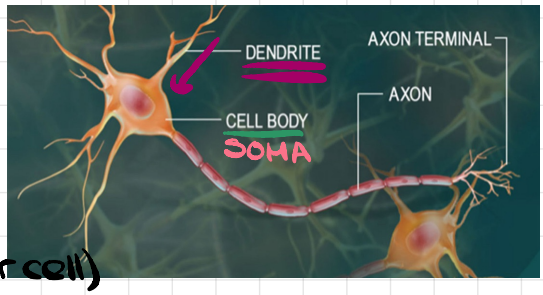
1. **Will-driven reactions: Central** processing of information from sensory system followed by **conscious or automated** reaction.
   → requires a conscious decision making & evaluating

2. **Autonomous reactions: Peripheral** processing of information for **fast reaction** based on **reflexes** directed from the spinal cord.
   → reflexes / autom. responses
   exmp.: knee reflex, heart rate chng.

# Neurons - Building Blocks of the Nervous System

neurons = charged cells

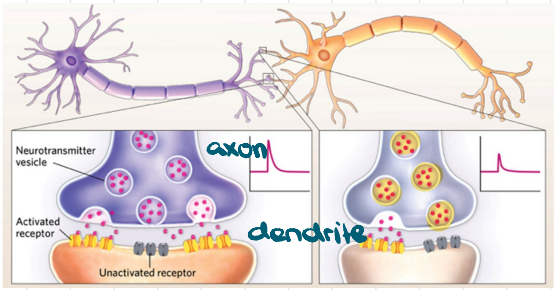
↳ nervous tissue consists of neurons
- conduct electrical signals
- whereby passing info through the body




Components of the neurons:
- **Dendrites**: receiver, input antenna
  ↳ receives signals from other neurons / CNP, PNS / a sensory receptor (touch, hair cell) towards cell body
- **Axon**: sender, output antenna
  ↳ send signals to another neuron / target cell (ex. muscle cell) away from cell body

# Synapses - the Junctions between Neurons

↳ where two things meet
↳ where a dendrite & an axon meet




1. Neuron A sends an electric impulse
2. this triggers a release of a chemical signal (neurotransmitters)
3. transfer of neurotrans. from axon to dendrites (Neuron B)
4. in Neuron B, because of action potential the next neuron can be activated with its own electrical impulse

↳ one neuron can have up to tens of thousands of synapses

**neurotransmitters: information flow by 2 types**
- excitatory: stimulating electrical signal → makes other neurons more likely to fire
- inhibitory: discouranging e.g. in other neurons

(correlates to output f.e. muscles)

**Spinal Cord** → contains neuron of cell bodies, bundles of axons & other cells

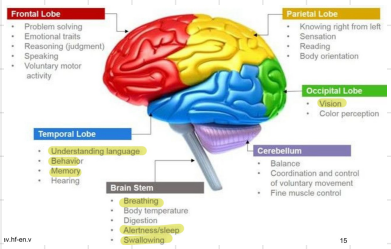
↳ responsible for:
- ▹ transmission of signals to & from brain
- ▹ command of reflexes (without brain) for autonomous reactions

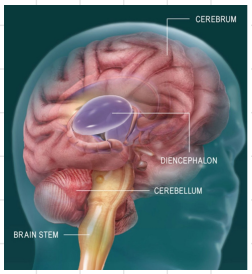
# Brain Regions

↳ brain directs the body's internal functions (hunger, hormones, heart rate), integrates sensory impulses (vision, hearing, smell) & information to form perceptions, thoughts & memories for self-awareness, speech, locomotion (movement). ↳ to understand what the senses mean. higher intellectual

↳ 4 parts
- Cerebrum (Grosshirn): conscious control for action (consciousness: ability to consider ourselves & outer world, functions) (senses, language, planning, emotions, remembering)
- Diencephalon (Zwischenhirn): drives & internal regulation (hunger, thirst, temperature regulation, hormones, stress, sex drive)
- Cerebellum (Kleinhirn): body movements, balance & speech coord. (keeps you upright, corrects movement errors)
- Brain Stem (Stammhirn): basic internal functions, reflexes (breathing, heart rate, blood pressure, swallowing, urination reflex, coughing, sneezing)
  ↳ relays signals from spinal cord

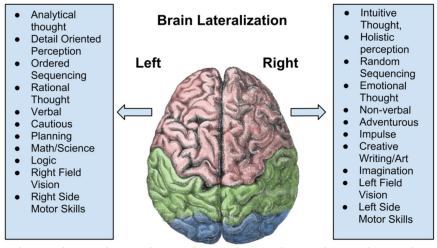
# Cortical Regions:




# Lateralization of Brain Functions

Some types of tasks seem to be performed better by one side of the brain than by the other:

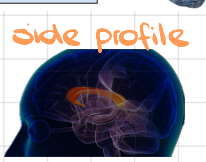



Nielsen, J. A., Zielinski, B. A., Ferguson, M. A., Lainhart, J. E.,

## Corpus callosum

connects & coordinates right & left hemisphere



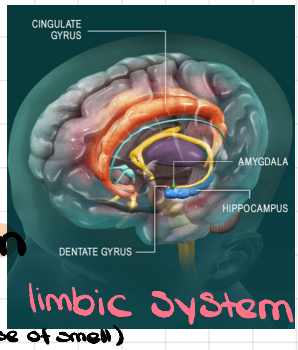

## Inner Regions of Brain

↳ connects perceptions to complex thought, memory & emotion

limbic system: processes emotions & creates drive (Antrieb)

↳ involved in learning & memory is relevant in olfaction (sense of smell)

key word: emotions




# The High Path & Low Path of Information Processing

happens in the limbic system: low precortical path

→ stimulus → thalamus → amygdala → immediate emotional reaction

↳ information is evaluated before conscious thinking

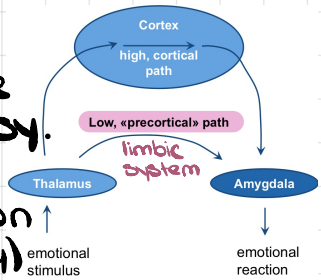
→ fast, automatic, based on past experiences, immediate emotional reaction

also called: emotional conditioning

high cortical path: conscious reflection

stimulus → thalamus → cortex → conscious evaluation → action

↳ slower, controlled, reflective




## Senses

→ specialized cells → able to receive a stimuli → translate into signals for nervous sy.

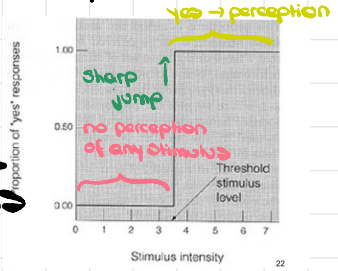
→ nerves send signal to brain

↳ sight, sound, smell, taste, touch, proprioception (position of body)

## Perception threshold for sensory stimulation

↳ threshold depends on (minimal sensory stimulation):

- the sensory system involved: different senses have different minimum detectable levels
- physical aspects: example: brightness of light, duration of sound, environment distance
- individual factors: age, fatigue, health, attention

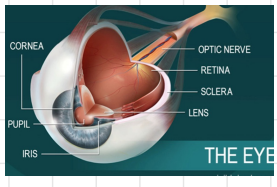



## Sight

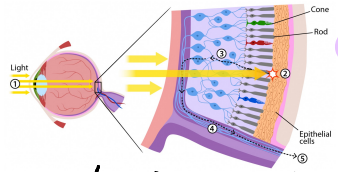
→ light into signals → pupil dilation regulates the amount of light → lens curving: regulates focus

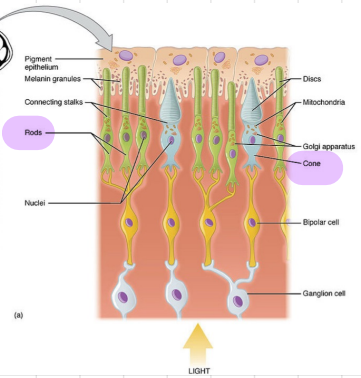
→ retina: nervous tissue contain. photoreceptor cells

→ visual cortex: forms visual image



# Photoreceptors: Cone & Rod Cells




**Cone cells:** concentrated in centre
- vision in bright light
- high resolution for details
- colour vision

**Rod cells:** concentrated in outer areas (of retina)
- vision in low light
- low resolution for details
- pheripheral vision
  ↳ 500-1000x more sensitive to light than cones

## Dark & Light Adaption

→ in visual physiology → ability to adjust various levels of light

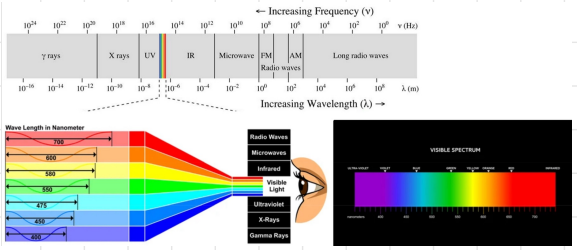
Dark Adaption: takes 20-30 min fully adapt from bright to dark → $10^3 - 10^6$x more sensitive → progressive decrease in threshold with time in dark

Light Adaption: takes 5 min

**Red Light:** optimal for illumination → reduces need for adaption (night)

## Perception of Color:

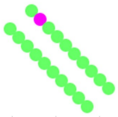




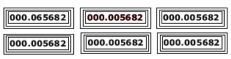

## Preconscious Organis. of Visual Perception

Gestalt laws ↳ symmetry: einheitlich (unitization) of lines → deviation stands out

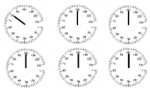
color: unitization by color → change stands out



## Digital vs Analogue Display



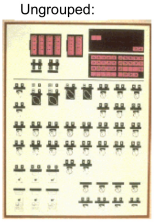

Precise, can be processed by machines



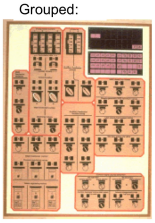
Intuitive, at one glance, visible trends

## Grouping of Info acc. to Functional Units

Ungrouped:



Grouped:



## Contrast in Oper. Conditions



**Sound** receives sound waves → mechanic vibration of membrane (ear drum) → transmitted as vibrations of auditory ossicles → that tranfer pressure waves in the fluid of cochlea → detected by specialized hair cells → transm. to brain

## Design for Auditory Alerts

→ driving

↳ affective when vision already occupied to avoid overload in envir. of low visibility (dark, smoke)

**Auditory Icons:** natural / familiar sound → metaphorically represent objects / actions → relying on intuitive association (exp. sound when deleting)

**Earcons:** abstract sounds convey info → different tones for diff notifications
→ consistency & learnability are key

**Speech Displays:** voice messages can provide detailed info → concise, clear & avoid overload with information

# Design of Sound Information

↳ for alerts / urgency

- **temporal patterns:** rhythmic patterns, faster repetition → high urgency
- **pith & loudness:** higher pith & greater loudness
  ↳ not to be overused → avoid alarm fatigue
- **escalating alarms:** start: low intensity, gradually increase in volume or frequency → if user doesn't acknoledge them → prevents startling & gives user time to respond

side note:

Benefits of Sound vs. Vision in Design

zh aw School of Engineering ZAV Zentrum für Aviatik

- Hearing is special among the senses, as sound can travel a long way and is propagated through air, ground and water. It "goes" around corners works also at night and . "Sounds give you **sensory input that is not limited by field of vision**" (Horrowitz, 2012).
- "You hear anywhere from **20 to 100 times faster than you see**, so that everything that you perceive with your ears is coloring every other perception you have, and every conscious thought you have. **Sound gets in so fast that it modifies all the other input** and sets the stage for it." (Horowitz, 2012)
- The brain's auditory circuitry is less widely distributed in the brain than the visual system. Sound gets routed to **pre-cortical areas** of the brain that deal with very basic functions, where **emotions are generated**, and no conscious thinking is involved.
- "Humans are emotional creatures and emotions are **evolutionary 'fast responses'** — things you **don't have to think about**.
- Sound hits you in the gut but is **also rich with patterns that carry information**.

# Sensory Mismatch (eye - ear)

↳ motion sickness: cause different messages from eye & ear

↳ spatial disorientation: pilot's perception not aligned with reality
→ position, motion, altitude → causes sensory mismatch

# Touch

specialized receptor cells detect tactile sensations → touch, pressure & vibration, pain, itch, tickle & temperature

# Smell

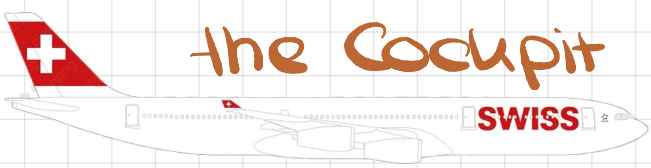
specialized nerve receptor of nasal cavity

↳ chemical in air bind to receptors & trigger a signal that travels to → olfactory bulbs with neuron cell bodies transm. info towards olfactory area of cerebral cortex

# Taste

chemicals from food enter the papillae & reach taste buds → specialized cells inside taste buds activate nervous receptors → signal trans. via nerves & the m. o. → brain

# Team performance in the Cockpit 4




Goals
↳ understand why teamwork in the cockpit is critical for flight safety
↳ Practical Crew Resource Mngm. (CRM)
↳ focus on communication, coordination & situation awareness

## Characteristics of the pilot profession

responsibility, teamwork, resilience, high ability to concentrate, ability to make deci., structured communication, technical understanding, decision making

Human Factors strongly influence crew performance
↳ everything pilots do in cockpit is shaped by human abilities & limitations

5 core Human Factors skills are essential

- communication: clear, concise communication between: pilot ↔ co pilot ↔ crew ↔ ATC
- teamwork: cooperation & mutual support for an effective crew
- attention mngnt: ability to focus attention on several tasks simultaneously / in a rapid succession (serial multitasking)
- error mngt: recognising, preventing & correcting mistakes early to reduce risk
- decision-making: making sound decisions under pressure

## Two pilots in airline cockpits

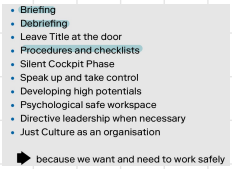



**WHY**: multi-crew operation is still essential
- safety: redundancy, monitoring
- workload distribution
- handling complexity of modern a/c
- CRM (Crew Resource Mngm.) effective use of all available resources to ensure efficient flight ops

**WHAT**: key roles & tasks performed by pilots in multi crew setting
- task sharing: of PF/PM (one controls the a/c, the other communication, checklists)
- cross-check & verification
- communication (briefing, call-out, confirmation)
- decision-making (joint assessment)
- automation mngmt: (monitoring & using autopilot)

**HOW**: pilots collaborate & ensure effective operations
- CRM principle (is how pilots work together using communic., teamwork, procedures & all available resources to fly safely)
- SOP's (Standard Operating Procedures): standardized actions, reducing ambiguity
- Briefing & Debriefing: shared plan & model
- Trust & Teamwork (cooperation, mutual support)

## Work safely as a Team:



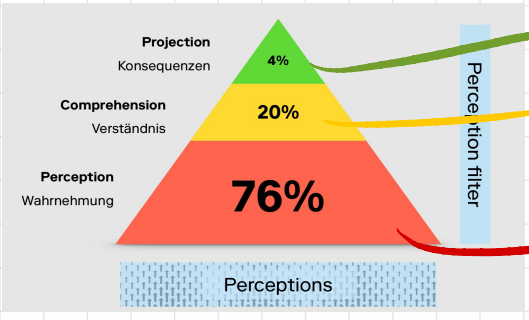

→ share the learnings, technology is a challenge, so is environment

## Pilot mistakes:

(siehe slides pg. 17 - 21)

↳ Human error causes upto 70% of aviation accidents
↳ CRM training is essential to improve situational awareness, workload mngmt., team communic.

## Situation Awareness




understand the data but don't know what to say

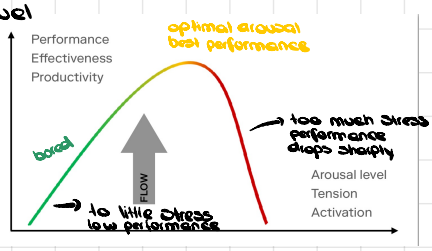
20% pilots perceive data but do not understand what it means

3/4 of situation awareness mistakes happen at perception level → pilots do not detect or notice something

# Stress mngmnt

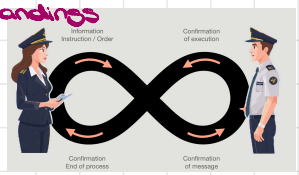
Yerkes-Dodson level → performance is best at moderate level of stress/arousal

Pilots must stay in optimal arousal zone




## Closed loop communication

avoids misunderstandings



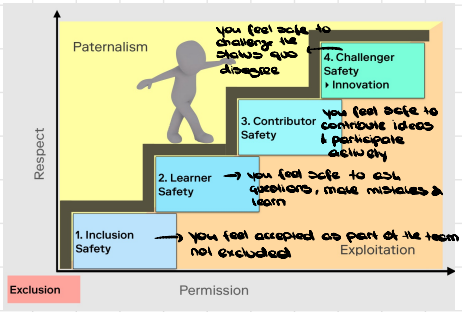

↳ ensures that the message sent is **received, understood & carried out correctly**

1. sender gives instructions
2. receiver repeats it back
3. sender confirms repetition is correct
4. receiver performs action
5. receiver confirms action completed

## Psychological Saf: knowing that you will not be punished or humiliated for speaking up with questions, comments, concerns or mistakes

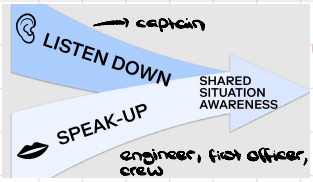
↳ 4 stages

Crew performance improves when pilots feel safe to speak up, ask, admit mistakes → better safety




### benefits of psychological safety

- **continuous learning**: people ask questions without fear (& admit mistakes)
- **succesful process change**: team adapts faster because they speak about problems
- **employee engagement**: employee feel valued when they're listened to, included in decisions
- **promote innovation**: team members dare to share innovation
- **interrupting error chains**: anyone can warn, challenge a mistake




What went wrong in Tenerife 1977?
CP (dominant) didn't listen to FO or engineer

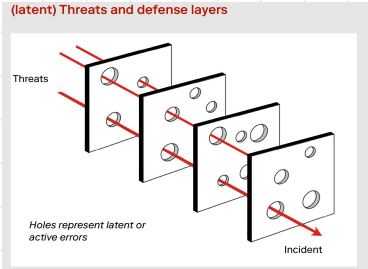
↳ a good captain actively encourages others to speak up incld. what captain may not like

why? in aviation safety depends on open communication together → shared situation awareness
then crew shares the same mental picture of situation

## Swiss cheese model

↳ in aviation, safety is protected by multiple layers of defence (procedures, checklists, training, teamwork, communication)
↳ each hole represents a weakness / threat
↳ an accident happens when the hole line up
→ meaning all defenses fail at the same time

→ accidents are not caused by one mistake → several small failures combine




## Strengthening the error chain

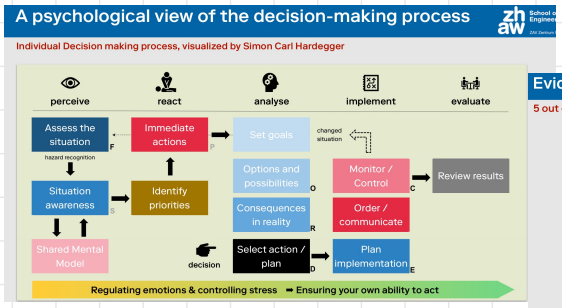
YOU → each crew member are a link in the safety chain
↳ human factors skills make the chain stronger

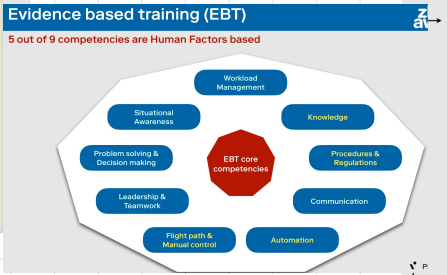



error happens but all of this acts as strong links that stop the error chain from progressing to an incident

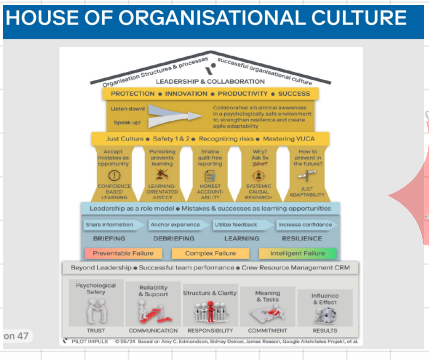
## Structured decision making (SPORDEC)

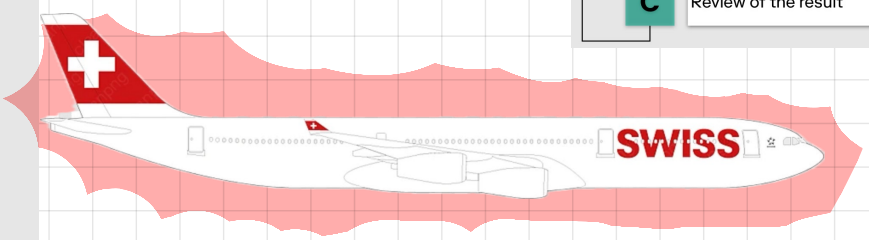
helps pilot think clearly & avoid errors under pressure by following a structured decision-making process




| | | |
|---|---|---|
| S | assess initial situation & goal(s) understand what is happening | Situation |
| P | take high priority actions do the urgent | Preliminary actions |
| O | evaluate possible solutions | Options |
| R | Pros & Cons ↳ evaluate them | Risks |
| D | Choosing the optimum solution | Decision |
| E | Implement the solution | Exexution |
| C | Review of the result | Check |



# Physiological aspects of human performance: 5
## OXYGEN & HYPOXIA

**History** Paul Bert: father of high-altitude physiology
↳ systematic study of low pressure affects on body
- effects of hypoxia on humans
- poisonous effects on oxygen
- DCS (nitrogen bubbles forming when p drops)

World War II → increased research because faster & higher flights → hypoxia became a problem
→ use of oxygen in flight → regular hypobaric chamber training (pilots)

**Physical Basics** → pressure drops with altitude → leads to insufficient oxygen → lungs cannot load enough $O_2$ into blood → organs become under-supplied = **HYPOXIA**

**Atmosphere Composition** → Oxygen: 21% → even though oxygen concentration stays 21% → the partial pressure drops with altitude → HYPOXIA

## Gas Laws

Boyle's Law $P_1 \cdot V_1 = P_2 \cdot V_2$ → problems with pressure equalisation → trapped air in body expands
pressure drops / volume expands
↳ pain with ear, sinuses, gastrointestinal problem

Dalton's Law $P_0 = P_1 + P_2 + \ldots + P_n$ → each gas contributes part of the total pressure
tot pressure drops → oxygen's partial pressure drops
↳ hypoxia

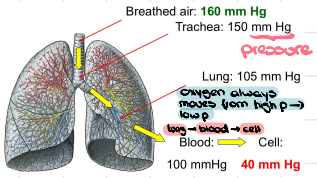
Henry's Law $\frac{P_1}{P_2} = \frac{Q_1}{Q_2}$ → less pressure → gases dissolved in your blood come out as bubbles (nitrogen leaves blood)
pressure drops → gas comes out of solution
↳ decompression sickness

## Lack of Oxygen

### Causes

| Type of hypoxia | Location of disorder | Cause | Incidents of occurrence |
|---|---|---|---|
| **Hypoxic** hypoxia | • Breathed air mixture (lungs)<br>• Alveolar membrane | Lack of $O_2$ (breathed air) enters lungs<br>Diffusion barrier | • Flight altitudes > 10'000 ft high altitude<br>• Lung disorders |
| **Stagnating** hypoxia | • Circulatory system<br>↳ cardiac arrest<br>↳ circulation | Disturbance of blood circulation<br>blood flow too slow | • Collapse, shock → g-force<br>• Permanent positive pressure ventilation → reduced blood flow to brain<br>• Vasoconstriction / dilatation<br>• Accelerations |
| **Anaemic** hypoxia | • Blood<br>↳ iron deficit.<br>↳ haemoglobin | Lack of functional haemoglobin<br>Hb missing | • Bleeding<br>• Anaemia<br>• Blocking of Hb (CO) |
| **Histotoxic** hypoxia | • Cell | Cell poisoning<br>toxins prevent cells from using $O_2$ | • Cyanide poisoning (potassium cyanide)<br>• Alcohol intoxication |

### Partial Pressure of Oxygen

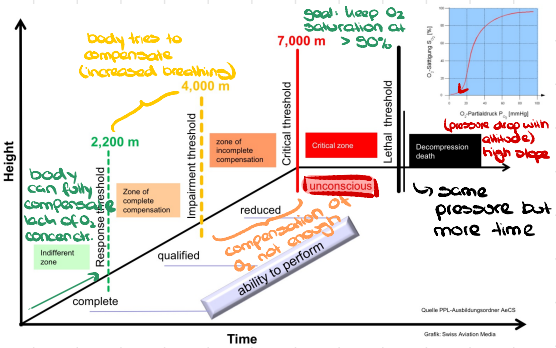



if one of the steps becomes too low (ambient p lower than p of your lungs)
→ the next step cannot receive oxygen

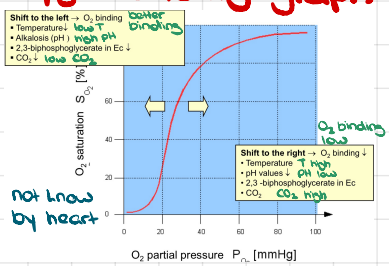
Partial pressure of oxygen at sea level:
= (21 x 760 mm Hg) / 100 = 159.2 mm Hg
21% $P_{tot}$ = partial pressure of $O_2$
Partial pressure of oxygen at 34,000 feet (10,800m):
= (21 x 190 mm Hg) / 100 = 40 mm Hg !
21% $P_{tot}$ = partial p of $O_2$ at

Note: If the partial pressure of oxygen in the blood drops below 40 mm Hg, the body is unable to absorb oxygen any more; in such a case, the cells even begin to lose oxygen !

### Threshold & zones




### Oxygen binding graph




### Phases of Hypoxia

❶ General retardation ↳ still reversible once oxygen
fully reversible

❷ Disturbances and performance errors
fully reversible ↳ judgement & perception drop

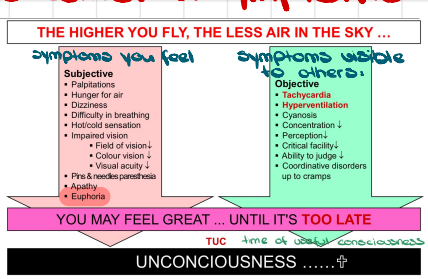
❸ Failure ↳ loss of consciousness
irreversible

| Pressure column | | Pressure (hPa) | | Hb saturation | |
|---|---|---|---|---|---|
| Meters | Feet | $PO_2$ | $PO_{2\,alv}$ | % | $O_2$ supply of organs |
| 0 | 0 | 213 | 137 | 98 | Sufficient supply |
| 3,048 | 10,000 | 146 | 81 | 90 | |
| 5,486 | 18,000 | 106 | 50 | 72 | Insufficient supply (lack of oxygen) |
| 6,706 | 22,000 | 90 | 44 | 65 | |

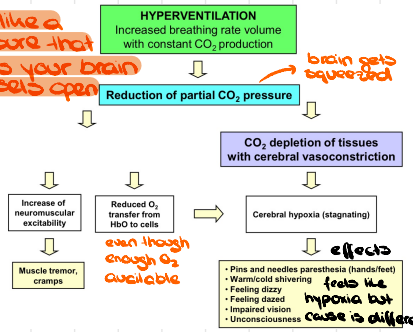
### Hyperventilation

↳ breathing too fast / too deep without producing more $CO_2$

### Indication & symptoms




$CO_2$ like a pressure that keeps your brain vessels open




### Time of useful consciousness (TUC)

→ when oxygen becomes low you only have short time before your brain stops working & you pass out

| Altitude | Passive DAeC (1999) | Passive German Air Force | Active |
|---|---|---|---|
| 43,000 ft | ~ 10 sec | ~ 15 sec | ~ 5 sec |
| 35,000 ft | ~ 45 sec | ~ 90 sec | ~ 30 sec |
| 30,000 ft | ~ 90 sec | | ~ 45 sec |
| 25,000 ft | ~ 3 min | ~ 3 - 5 min | ~ 1 min |
| 18,000 ft | ~ 30 min | ~ 30 min | ~ 10 min |

Begin of insufficient $O_2$ supply | Subjective warning signals (symptoms) | Incapable of action ✝
Practical self-rescue time | Additional external rescue time
= TUC or EPT*)

# Prevention

- pressurised cockpit
- oxygen respiration
- pressure suit

- **Gradual hypoxia**
  - Difficult to recognise !
  - Knowledge of subjective symptoms may save life
- **Explosive Hypoxia**
  - Manifests itself normally as an emergency
  - Can hardly occur unnoticed

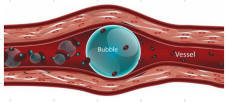
→ never occurs in a noticeable way

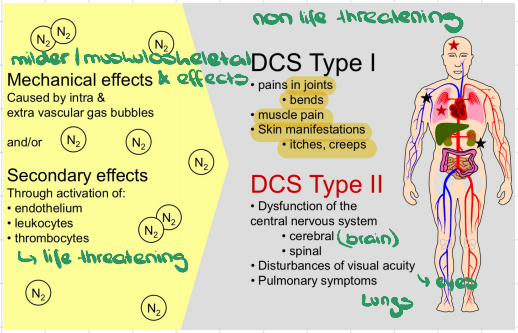
# Decompression sickness (DCS)

↳ when external pressure drops, dissolved gas comes out of solution
(amount of gas dissolved in a fluid is proportional to the partial pressure of the gas above the fluid)

↳ dissolved nitrogen in your tissues forms bubbles

- nitrogen can be dangerous: they block blood flow, press on nerves, activate inflammation
  ↳ even small bubbles can cause pain




## Symptoms by Organ

**DCS & joints ('bends')**
- Localised, deep pain
- Affected joints: knee > shoulder > elbow > wrist > hip
- Rubbing increases pain
- Pressure relieves pain

**DCS & skin ('creeps')**
- 'Pins and needles' at high altitudes
- Disappear again spontaneously

**DCS & Lungs ('chokes')**
- Impression of difficult breathing
- Limited inhalation
- Pain under the sternum
- Cough

**DCS & heart**
- Cardio-vascular-collapse

**DCS & brain ('staggers')**
- Paralysis
- Crap attacks
- Paresthesia
- stroke-like impressions
- Blurred vision
- Headache
- Collapse… and much more.

↳ **Note:** DCS symptoms can appear hours later (up to 24h later) (diving)
→ repeated exposure to pressure change & physical strain (exercise, heavy lifting) can trigger symptoms
→ each exposure dissolves & releases more nitrogen

## Factors which increase likelihood of bubble formation

physiological factors
- Age > 40
- Dehydration
- ∅ denitrogenation (pre-breathing $O_2$ before exposure)
- ♀ gender
- Height (taller → increased risk)
- Hypoxia (low oxygen → vessel constrict)

environmental
- Physical activity (excercise increases nitrogen uptake)
- Rate of climb (↳ fast ascent)
- Diving → super-saturated with nitrogen
- Temperature ↓↓↓ (low temp → slow circulation)
- Obesity (↳ more fat tissue → more nitrogen)
- Repetition, duration (↳ long exposure)

## Prophylaxis

- No stay in a high pressure environment
- (diving !) rules — min waiting time before flying
  - < 2 bar → 12 h latent period
  - > 2 bar → 24 h latent period
  - > 2 bar repetitive → 36 h latent period
- Pressurised cockpit / suits (reduce p drop)
- 100 % prior oxygen breathing
- Slow ascent; brief stay (→ Hypobaric chamber therapy)
- Alternative to HCT: reduced oxygen breathing device (ROBD) → (→ holds body into hypoxia → by giving less oxygen → without lowering the pressure)

DCS Type I → must be treated
- 100 % Oxygen → (flushes nitrogen out of body)
- Physical restraint → (stay still)

Symptome > 2 h
If symtomps more than 2h then ↓ DCS II

**DCS Type II**
- 100 % Oxygen
- Recompression (hyperbaric chamber) → (increase pressure so nitrogen bubbles shrink)
- Volumen substitution → (N fluids support circulation)
- Cortikosteroids, Tc aggregation inhibitors ???
- Intensive care measures (↳ reduce inflamm.) (↳ ICU?)

# Hypobaric chamber

↳ a room where air pressure can be lowered to simulate high altitude

- Demo for oxygen deficiency: used to train pilots (recognise early hypoxia signs)
- explossive decompression: can simulate a sudden drop in pressure
- research & development: used by medicine & military

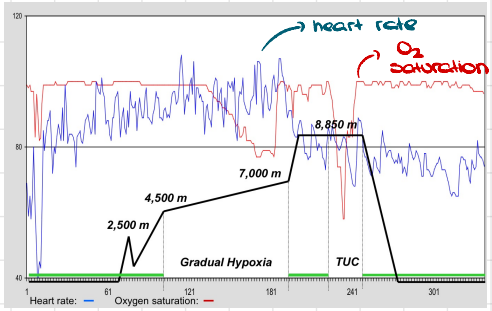
## Training sequence

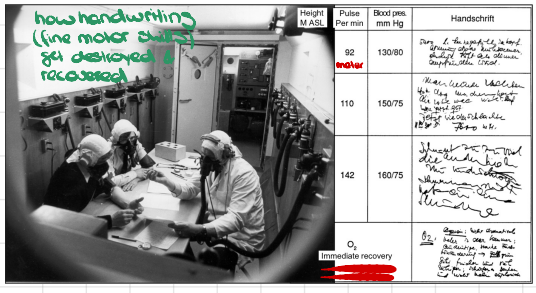
1) Anamnesis → medical check
2) examination → blood p, pulse, $O_2$ saturation baseline
3) Pre-oxygination → breathe pure $O_2$ to get rid of nitrogen
4) enter chamber
5) monitoring → pulse oximetry ($O_2$ saturation)
   video → behaviour

# Oxygen deficiency demonstration
# Explosive decompression

pilots do this training to ensure they react instantly when $O_2$ drops

↳ for correct undelayed response in the event of hypoxia symptoms & explosive decompression




**Decompression sequence =** (depends on)
**f ($V_C$, $F_L$, Δ P, flight altitude)**
- Pressurised cockpit volume
- Size of leak (↳ big more → big decomp.)
- Pressure gradient → inside to outside (↳ small cockpit → faster decomp.)
- Flight altitude

**Physiology** ($P_{O_2}$ drops)
- Acute oxygen deficiency
- Decompression sickness (DCS ↳ nitrogen)
- Complaints due to gas expansion in the gastrointestinal tract

**Physics**
- Explosion-like bang → (air rushes out quick)
- Suction effect → (some may be sucked in liquid)
- Development of fog → (moisture in air condenses quickly ↳ expanding air cools rapidly)
- Drop in temperature

**Emergency measures** (must do)
- Emergency descent
- Oxygen

↳ small cabin (volume) = more dang.

# Final instructions

after hypoxia / decompr. chamber training

- No sports activity x 24h → (can move nitrogen bubbles for)
- No parachuting x 24h → (jumping = altitude changes)
- No flying as PIC x 24h (pilot in command) → (temporarily impair judgement)
- No military flight service as pax on same day (normal flight)

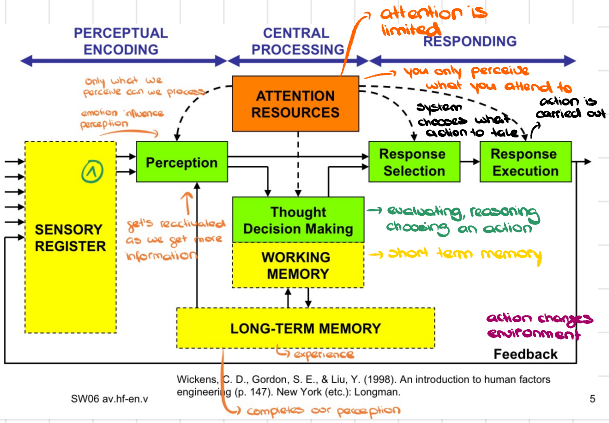
SWISS AIR FORCE TEAM
PATROUILLE SUISSE

# Information Processing: Perception, Attention & Situation Awareness

6

Goal: know how information is processed in human perception

## Perception → Model of Information Processing




Wickens, C. D., Gordon, S. E., & Liu, Y. (1998). An introduction to human factors engineering (p. 147). New York (etc.): Longman.

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How is information formed in human perception?
↳ 3 steps: sensory input → attention selects what is important → the brain organizes & interprets the signals

What bottleneck & biases affect situation awareness?

What countermeasures are recommended? ↳

| SA Problem | Description | Countermeasure |
|---|---|---|
| Limited attention | Cannot process everything | Prioritise, reduce distractions, CRM |
| Working memory limits | Forgetting, overload | Notes, checklists, chunking |
| Tunnel vision | Focus too narrow | Systematic scanning, cross-checks |
| Confirmation bias | Seek expected cues | Seek opposing evidence |
| Expectation bias | Perceive what you expect | Slower decisions, readbacks |
| Anchoring | Stuck on first idea | Regular situation updates |
| Complacency | Reduced monitoring | SOPs, reminders, cross-checks |
| Automation bias | Blind trust in systems | Monitor modes, manual skills |

## What is Perception?

Perception involves **recognizing, organizing, and interpreting sensory information** to make sense of the situation in a given environment.

A selection of sensory stimuli such as sights, sounds, smells, and textures is used to **create understanding** of the world around us is formed.

A combination of sensory input and cognitive processes (use of memory , experience, and expectation) is used to create a **coherent experience of reality**.

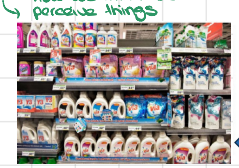
Perception is a key element in how we navigate, learn, and respond to our surroundings - from simple reactions to complex decision-making.

Perception **varies across individuals** due to differences in biology, past experiences, and cultural background, all of which can influence how we interpret the same stimulus.

Goldstein, E. B. (2014). *Sensation and Perception* (9th ed.). Cengage Learning.

## Constructive Perception: How the brain sees more than it receives

↳ how we think we perceive things



↳ how visual information is actually perceived




→ brain does not actually see everything
small amount of sharp visual
your brain fills in the missing information
↳ the brain predicts what should be in environment
→ based on your past experiences context & expectations



## Model of Information Processing (IP)




## Visual Perception (1/2): Bottom-up Processing of Info

Gaze Analysis: which elements attract users attention first? How quickly can they find the information they need? time? → to process or interpret the information?

Fixation maps: shows focus of visual attention

Heat maps: provide visual summaries where & how long people look at

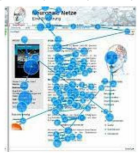


*Diagram 1:* **fixation map** with fixation duration and saccades




*Diagram 2:* **heat map** based on fixation map show total duration of fixations

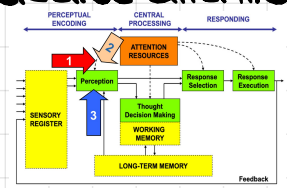
## Process Involved in Conscious Perception

3 interacting processes

1. bottom-up (data driven) processing → saliency of cues → some stimuli automatically attract attention because they are unusual, bright, loud
→ these stimuli are processed first even if they're not relevant

→ centrality of information → information which is centrally located in the visual field
→ more likely to be perceived

2. selective attention: because attentional resources are limited, the brain must select what enters conscious awareness




what determines selective attention? your goal, task, motivation
↳ you actively focus on information that seems relevant for you

3. top-down processing (conceptually-driven): perception is shaped by prior knowledge, expectations, experience
schemas/context

## Visual Perception (2/2): Top-down Processing of Info

top down processing: brain uses prior knowledge, context & expectations to interpret incomplete or distorted sensory input

↳ normally perception starts with sensory input (bottom up) → brain adds knowledge from memory to interpret what it sees

How do we do this? Schemas stored in long-term memory are used to reduce the amount of info that needs to be processed → this shortcut comes at the risk of over-simplification by stereotypes

**Schemas:** → are knowledge representations in long-term memory
don't store every detail → meaningful essentials → built from experience
→ contain general knowledge about objects, events, situations
↳ organise knowledge hierarchially into categories & subcategories

**Scripts:** describes a typical sequence of events (steps) (in a familiar situation)
↳ like a restaurant

**Mental model:** how a system works → describes components of a system, relationships between components
↳ system based
↳ it generates expectations of how a system will behave allowing anticipation of events and consequences

**Categorisation:** process of grouping objects, events, ideas based on shared characteristics

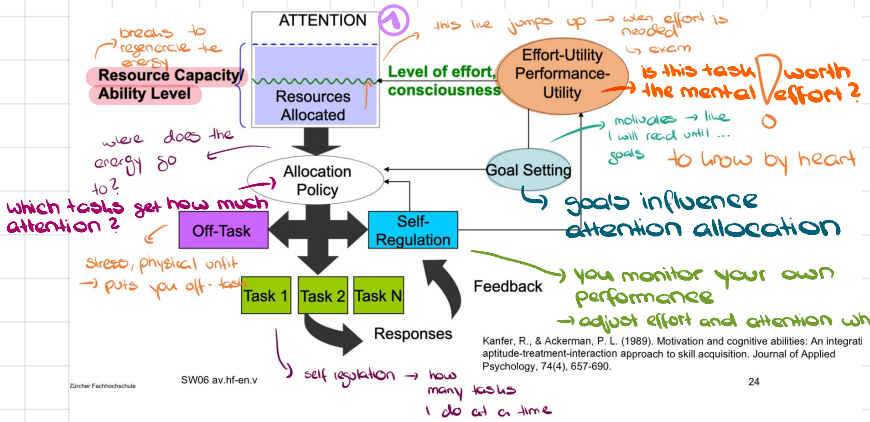
## Attention:

**attention:** focusing your limited mental resources on some things and not on others (brain must select)

**concentration:** actively keeping your attention on one task or problem
↳ 2 types of attention: voluntary: you choose what to focus on
involuntary: something grabs your attention

↳ in information processing terms ↳ attention is either a filter or a limited resource

**inattentional blindness:** you don't notice something clearly visible because your attention is focused elsewhere (because of lack of attention)
↳ more prevalent with low working memory capacity & high workload



Kanfer, R., & Ackerman, P. L. (1989). Motivation and cognitive abilities: An integrati aptitude-treatment-interaction approach to skill acquisition. Journal of Applied Psychology, 74(4), 657-690.

↳ attention = limited capacity
↳ when tasks demand more than this capacity → performance drops

**ability level:** maximum attention capacity

**attention → task performance → responses**
- you notice errors
- performance feedback increases

**bottleneck:** a stage where processing is limited → limited information can pass at one time → forcing selection
↳ cause of inattentional blindness

## Situation Awareness

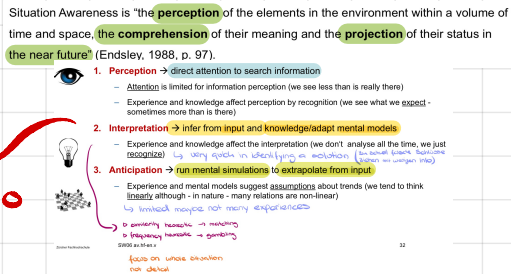
↳ describes how well a person understands what is happening, what it means and what will happen next

Level 1: noticing relevant elements in the environment → 1-SA perception
Level 2: integrating perceived data with knowledge & experience & with mental models → 2-SA comprehension
exmpl: decreasing airspeed + rising pitch = risking of stall
Level 3: using the mental picture to simulate future → 3-SA projection
(what will happen next if nothing changes)

SA for pilots: to be informed about → systems, procedures, ATC, PAX

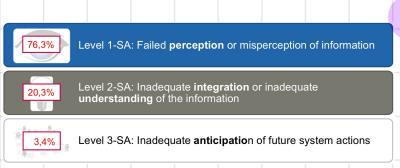
↳ environment → SA(1,2,3) → decision → performance of actions → feedback

use mental models to interpret perceived info quickly (patterns)

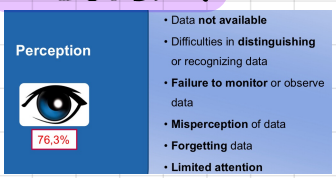


# Where SA goes wrong?

↳ in the first 2 levels




## ↳ Level 1:




→ attention limits
→ distractions
→ inattentional blindness
→ high workload

! failure to monitor → most frequent error (35%)

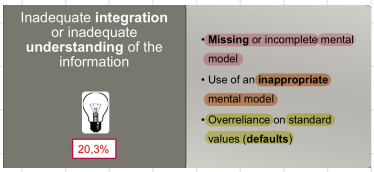
↳ information was available → but the person did not look in time → because of attention limits

Perception-related problems (SA-Level 1) due to **limited attention**

↳ all these linked limited attention

| | | |
|---|---|---|
| **Selective attention** | Tunnel vision, missing information | → focus on one thing & filter the rest |
| **Focused attention** | Fixation; distraction | → focus too strongly on a single element (fixation on one warning → missing critical cue) |
| **Distributed attention** | Limitation in multi-tasking; lack of timely monitoring | → try to monitor multiple things at once |

## ↳ Level 2: → you have the information but you interpret it correctly

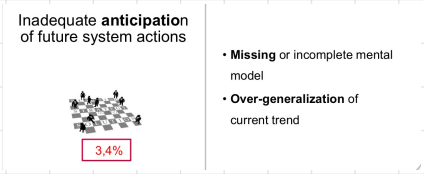


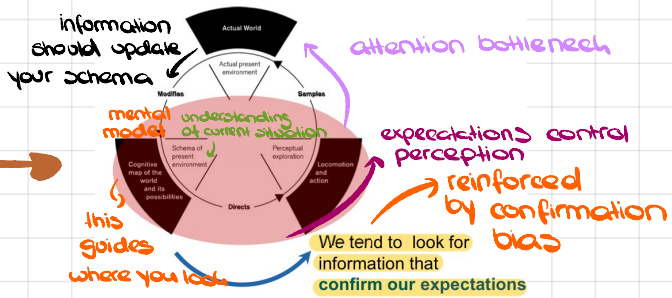

↳ don't fully understand how the system works
↳ use an old or incorrect explanation to a new situation
↳ assume standard behaviour instead of checking reality
↳ thinking errors

↳ perception & understanding work as a loop not straight line

Risk: **confirmation bias**

## ↳ Level 3:




# Indication of Loss of SA

- **Ambiguity** - information from two or more sources does not match
- **Fixation** - focusing on one task at the expense of the other
- **Confusion** - uncertainty or confusion about the situation, often combined with fear or discomfort
- **Lack of required information**
- **Loss of control** for critical tasks
- **Missing** an expected checkpoint or target
- **Failure to eliminate discrepancies** (e.g., contradictory data or personal conflicts)
- **Bad gut feeling**, because things are not going quite right

Worksheet — School of Engineering

1a) How is information processed in human perception?

1b) What bottleneck and biases affect situation awareness (mention 5 aspects).

→ - structure (x- list) / allocate enough time
- monitor at predefined gates
- present relevant situations in training - collect all info

What countermeasures do you suggest? Mention 5 aspects with regard to information processing.

↳ we tend to look for info which confirm our expectation
↳ bottleneck selective information (fixed / narrow tunnel vision)
↳ inner state: distraction, stress
↳ over-routine → debrief
↳ a lot of info / unrelated info
↳ external factors (time pressure, noise, lighting)

familiarity, mindset („easy", well-known, nothing new)

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# Factors that minimize Loss of SA

- Good **briefing** & **debriefing** → most important part of evaluating our mental mode
- **Time management** (avoid overload)
- Be in good **health**
- **Minimization of distraction** and interruption (task coordination)
- **Communication** (closed-loop)
- **Checking** the mental model (anti-confirmation)

# Intercorrelation of diff. SA

| Interactive Scenario (E2S2.1 Crossing) | Self-Rating: SASHA_Q [score] N=16 | Query: SASHA_L Correct [%] N=16 | Gaze-based: ET Conflict Detection [min] N=14 | Implicit SA: conflict duration [min] N=14 |
|---|---|---|---|---|
| Self-Rating: SASHA_Q [score] | 1 | 0.1508 | -0.0621 | -0.1985 |
| Query: SASHA_L Correct [%] | | 1 | -0.7932*** | -0.7095** |
| Gaze-based: ET Conflict Detection [min] | | | 1 | 0.8538*** strong relationship |
| Implicit SA: Conflict Duration [min] | | | | 1 |

**Table**: Pearson correlations between SA measurements in experiment 2
* p < 0.05; ** p < 0.01; *** p < 0.001 (Haeusler et al., 2022)

Finding:
**Low consistency** of **subjective rating** scale with other measurement methods for SA.

→ Easy to measure, but deficient, as lack of SA will only be realized when consequences occur.

# Methods to Measure SA

1) **Subjective Rating**
e.g., SASHA_Q (Dehn, 2008): ↳ controllers rate their own SA after the task ↳ perceived SA
6 questions
Scale from 0 (never) to 6 (always)

2) **Probe technique** for SA ↳ direct questions are asked
e.g., SASHA_L (Dehn, 2008): with/without freezing and blanking of the screen
e.g., "Do you see any non-conformance?" "Are there any conflicts between aircraft?" ↳ measures actual knowledge

3) **Gaze-based indicators** for SA: Eye-Tracking

4) **Implicit performance measures** for SA: behavioural observation, communication ↳ attention distribution
e.g., actions for solving a conflict or repeating an instruction about level-off altitude; time to solve a conflict
↳ SA derived from performance outcomes

| Item |
|---|
| 1) … I was ahead of the traffic. |
| 2)* … I started to focus on a single problem or a specific area of the sector. |
| 3)* … there was a risk of forgetting something important (like transferring an a/c on time or communicating a change to an adjacent sector). |
| 4) … I was able to plan and organise my work as I wanted. |
| 5)* … I was surprised by an event I did not expect (like an a/c call). |
| 6)* … I had to search for an item of information. |

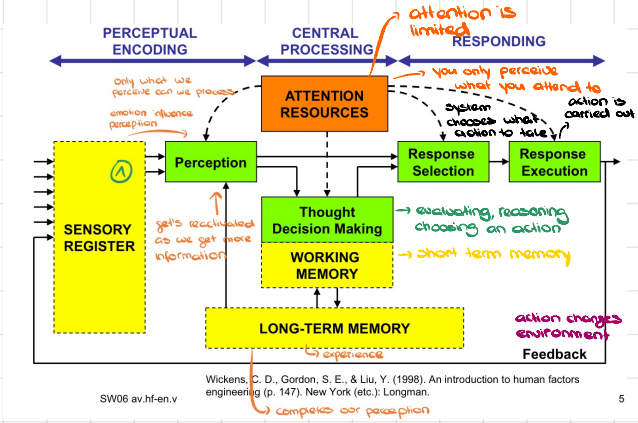
*Table*: SASHA_Q (Dehn, 2008)



*Image*: ATCO in an experiment using eye-tracking glasses

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# Information Processing: Memory & Learning, Action Control 7




Wickens, C. D., Gordon, S. E., & Liu, Y. (1998). An introduction to human factors engineering (p. 147). New York (etc.): Longman.

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## Memory

Human memory has processes & systems that are responsible for the storage, saving, retrieval & application of information as soon as the original source of info is not available anymore.

Info are: stimuli (sound, smell, image, word)
autobiographical details
generic knowledge about the world
specific skills (language)

**Attention** as a filter → determines which sensory inputs are processed further → without att. info doesn't move to short-term memory

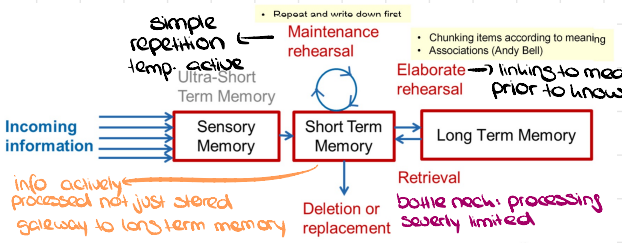
**Bottleneck / Selectivity** human processes resources are limited → not all stimuli is processed because of bottle neck only a subset of available stimuli is selected for processing

**Decision Task** signal present or not ?

## Sensory registers (ultra-short-term memory)

↳ act as temporary buffers for each sesen (vision, touch...)
they briefly store large amounts of raw sensory data immediately after simulation
→ purpose: no storage but selection → system holds info just long enough for the brain to decide what is relevant
↳ allows continous perception of environment despite limited cognitive resources

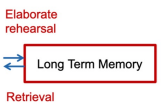
## Short term (working) memory




↳ attention required to select relevant info and suppress irrelevant stimuli → without attention, info neither stays in working memory nor reades long-term memory

↳ only small subset of sensory input enters working memory
↳ processing for transfer to long-term memory

## Long-Term Memory




- Long-term memory stores the acquired knowledge and trained skills procedures, concepts, motor skills developed through practice
- **Infinite storage capacity** and **duration**
- Storage according to **meaning**, remembering involves reconstruction
- Organisation of knowledge in semantic **networks**
- **Limited bandwidth** to transfer new memories to LTM

→ infinite storage → info available for years
→ not exact copies → remembering is a reconstructive process
→ concepts linked to associations.

↳ transfer of new info into LTM is limited
↳ effective transfer requires elaborate rehearsal in working mem.

## Rehearsal

Maintenance rehearsal: devoting just enough mental resources to keep information from being lost

Elaborative rehearsal: deep processing of information by use of previous knowledge, visualization

# Perception based on Recognition of familiar elements driven by schemas in Long-term-memory

↳ top-down perception & role of schemas

↳ perception is recognition based → strongly rely on familiar patterns



What patterns are we familiar with?

Perception draws heavily on **recognition** (i.e. top-down processing of information)

→ We see what we are familiar with / expect / feel a need for

- Memorizing is not like "producing a video"
- It is based on a **reconstruction** from known elements with as little input as possible

minimum sensory units as possible

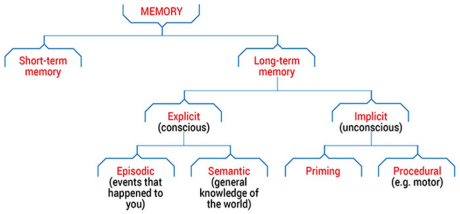
→ from long-term memory to perception → expactions, prior know.

perception biased toward what we expect

↳ different people may perceive different meaningful shapes in the same stimulus depending on their schemas

↳ perception may vary between individuals

## Types of Long-Term memory




**episodic:** connected to self, memory of events of personal importance, memory of everyday events (times, location, explicitally stateable)

**semantic:** categories → class of objects with common things bird → fly → feather → can move around ⇒ stores knowl. with little redund.

**classical conditioning:** learning process where neutral stimulus (ringing bell) combined with natural stimulus (food) that leads to a response

**procedural:** habitual response (tying your shoes)

**priming:** unconscious activation of one or more existing memories by a stimulus (smell of lemon → clean table)

**remembrance:** recall & recognition

recall: free recall from memory

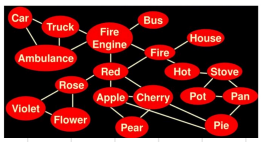
recognition: remembering upon presentation of stimuli

- Rememberance depends on the **number** of and the **strength of associations** between information units within the neural network
  → amount of **spreading activation** between neurons connected to unit to be recalled

  Recall of information is good, if ...
  - Well connected with many other memory units (many retrieval paths)
  - Often used/remembered
  - Recently used/remembered

### Spreading Activation Model

- Activation of long-term memory content occurs through mental links between concepts, formed by shared properties or associations.
- Shorter path between two concepts → stronger association im memory



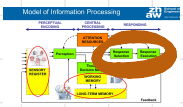

### Neuroscientific Perspective on Learning

- **Learning** = development of **neural networks** that enable new behavior in specific situations.
  (formation & modification of)
- **Effectiveness** of learning = **ease of reactivation** of new neural networks → "Use it or lose it!"
  learning is effective when newly formed neural networks can be easily reactivated
  - frequency of use of neural networks
  - pleasant consequence ↳ more accessible ↳ positive feedback stabilization of neural network

### Learning and Memory

- On the neuronal level memory is built when neurons are **simultaneously activated.** Hebb (1949): „**Cells that fire together, wire together**"
  - Synapses are high in plasticity. Stronger connections with more use. This enhances readiness for transmission and enables higher activatability.
  - Facilitation (Bahnung; Hüther, 2012): the more frequently neural connections are activated, the easier they get reactivated and the higher the capability for transmission
- **Remembering** is **re-activation** of neural networks.
- Knowledge is the readiness for activation of certain neuronal patterns of excitation within the large neural network.
- The more information is rehearsed (maintenance rehearsal), the higher its probability of being remembered. The more information is processed (elaborative rehearsal), the better it is remembered.

# Action Control




**KSA:**

- **Knowledge**: State of being **familiar** with something or aware of its existence, usually resulting from experience or study . The range of one's understanding or information (cf. declarative knowledge in LTM)
- **Skills** (Fertigkeiten): are learnt and include execution of specific activities and processes/procedures (cf. procedural knowledge in LTM)
- **Attitude** (Einstellung) : a relatively enduring and general **evaluation** of an object, person, group, issue, or concept on a dimension ranging from negative to positive. … They are derived from specific beliefs, emotions, and past behaviours associated with those objects.

**Ability** (Fähigkeiten): capacity to perform a physical or mental act.

**Competencies**: involve knowledge about targeted application of skills and abilities to adapt successfully to a specific situation

Analytic approach: e.g., apply new medicine
→ „**knowledge-based**"



Well practiced behavior pattern: e.g., standard mission of a rescue team
→ „**rule-based**"



Routine action, automatism: e.g., pull up a syringe
→ „**skill-based**"



### 1) Knowledge-based action (wissensbasiert)

- **When used:** New, unfamiliar, complex, or high-risk situations.
- **How it works:** Conscious reasoning, analysis, and planning.
- **Characteristics:**
  - High attention and working-memory demand
  - Slow and effortful
  - Flexible, but error-prone under stress
- **Example (slide):** Deciding *how* to remember a new PIN by thinking of different strategies.




**Knowledge-based**
Analyses, plans

Orient → Plan → Draft action → Perform action → Evaluate outcome

- Conscious action is taken
- Extensive attention required
- In situations when actor is inexperienced / task is complex and novel
  e.g., first driving lesson
- When risks are high
- Key for safety: analysis of all relevant information and consideration of all possible consequences

### 2) Rule-based action (regelbasiert)

- **When used:** Familiar situations with known procedures.
- **How it works:** Applying learned **if–then rules**.
- **Characteristics:**
  - Moderate attention required
  - Faster than knowledge-based
  - Depends on correct situation recognition
- **Example (slide):** *If* the pattern looks like an "L-shape in the middle", *then* use the learned rule to enter the code.




**Rule-based**
Flexible action patterns

Orient → Perform action → Evaluate outcome

- With practice of execution: well-trained skills for familiar tasks
- Recognition of learned signals and associated solution (motor program) → If-then association (if situation X, then action Y)
- Immediate retrieval of procedures/behaviours from long term memory that proved to be effective (reinforcement)
- Requires less attention than knowledge-based action control
- Key for safety: correct recognition of the situation

### 3) Skill-based action (fertigkeitsbasiert)

- **When used:** Highly practiced, routine tasks.
- **How it works:** Automatic execution via stored motor programs.
- **Characteristics:**
  - Minimal or no conscious attention
  - Very fast and efficient
  - Vulnerable to slips, interruptions, and context changes
- **Example (slide):** Automatically typing the PIN as a smooth finger sequence without conscious thought.




**Skill-based**
Automatisms

Orient → Perform action → Evaluate outcome

- Highly trained skills / routine tasks
- Unconscious execution of automated routine actions
- Stimuli directly trigger motor programs
- Schemes work as templates (Schablone)
- Minimal/no attention resources required
- Foundation for complex skills and multi-tasking
- Key for safety: matching of context with routines (if not, switching to rule-based or even knowledge-based control mode)

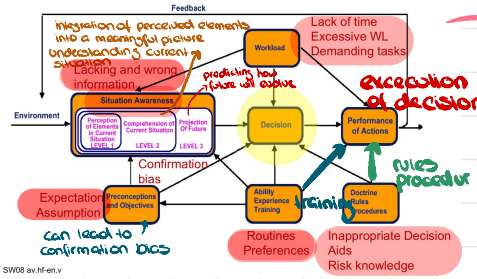
# Decision Making, Problem Solving, Research Approaches 8

## Decision Making exmpl:

↳ a process of reaching a judgement or choosing an option, sometimes called a course of action, to meet the needs of a given situation

19% of all air accidents could've been prevented, if a timely decision had been made to go around (Boeing 1993)

Elements of decision making:
1. Situation assessment / definition of the problem
2. Generating and considering multiple options
3. Selecting and implementing an option
4. Outcome review (feedback loop)




→ shows how decisions emerge from situation awareness & how human limitations & biases can degrade performances

↳ good decision depends on SA on all 3 levels

red → human factors failure

Decision making influenced by: situation awareness, ability training, experience, rules, procedures, workload

## Problem Solving

### Intuitive vs. Analytical Thinking

- Humans **do not choose** between systems freely; context determines dominance.
- Many decision errors occur when **intuitive thinking is used where analytical thinking is required.**
- Safe problem solving requires **knowing when to slow down** and engage System 2.

**Fast,**
**intuitive or instinctive,**
**emotional**
**low on energy**

↳ automatic
low energy demand
prone to biases & heuristics
↳ use time critical situation

**Slow**
**deliberative, logical,**
**high in effort**
↳ and demand

↳ more accurate
↳ easily degraded by fatigue
↳ non routine problem solving

Alcohol example: human reasoning not purely logical in abstract form (Cards)
↳ performance improves when a problem is framed in familiar, meaningful context
↳ typical error confirmation bias

## Model of Decision Making

### 1) Situation assessment / problem recognition

Before any decision is possible, the person must **understand the situation.**

- **Situation analysis**
  Gathering and interpreting relevant information from the environment (linked to **Situation Awareness Levels 1–2–3**).
- **Building a mental model**
  Forming an internal representation of:
  - what is happening,
  - why it is happening,
  - how it might evolve.

⚠️ Errors here propagate directly into poor decisions.

### 2) Make a decision

Once the situation is understood, a decision is made using **one of four decision modes:**

**Automatic**
- Fast, unconscious, routine
- Based on habits and skills
- Efficient but vulnerable to slips and mismatches

**Rule-based**
- Application of learned **if–then rules**
- Requires correct situation classification
- Fails if the wrong rule is selected

**Analytical**
- Deliberate comparison of options
- High cognitive effort and time demand
- More robust for novel or complex problems

**Creative**
- Generation of **new, non-standard solutio**
- Used when no rule or procedure fits

### 3) Selection of the action

- Choosing the most appropriate action from available options
- Strongly influenced by:
  - time pressure,
  - workload,
  - training and experience,
  - risk perception.

**Core message (exam-relevant)**
- Decision making is **not just choosing an action**, but starts with **understanding the situation.**
- Humans switch between different **decision modes** depending on familiarity, time pressure, and workload.
- Many errors occur because people **use an inappropriate decision mode** (e.g. automatic instead of analytical).

If you want, I can:

## Research Approaches for Decision Making

### Normative Approach

### Descriptive Approach

**1) Normative Approach to Decision-Making**

↳ how decisions should be made by a perfectly rational decision maker

Focus solely on **rational decision-making process**

↳ assumes: complete info, unlimited time, unlimited cognitive resource

- Optimal decision-making process to be a "perfect decision maker"
  ↳ fully analytical
- Requires much attentional resources, deliberate problem solving and time
  ↳ high attentional resource
- E.g., cost-benefit analysis for buying a house or pros and cons for next Covid-booster

**2) Descriptive Approach to Decision-Making**

School of Engineering
ZAV Zentrum für Aviatik

Not how decisions should be taken in theory (normative approach), but how decisions are actually taken **in practice** (not theory).

**Describes heuristics** (rules of thumb) and **biases** found in decision making processes due to reliance on **intuition**.

↳ satisficing: instead of searching for the best possible option → choose the one with minimum requirements

**Heuristics**
- **What they are:**
  General **mental shortcuts** or rules of thumb used to simplify decision-making.
- **Purpose:**
  Reduce cognitive effort when time, information, or attention is limited.
- **Nature:**
  Can be **useful and adaptive**, but may also lead to systematic errors.
- **Timing in cognition:**
  Used **during reasoning and judgment** to reach a conclusion efficiently.
- **Examples:**
  - *Anchoring* (relying on an initial value)
  - *Availability* (judging likelihood by ease of recall)
  - *Representativeness* (judging by similarity to a prototype)

➡️ Heuristics are **strategies.**

**Confirmation Bias**
- **What it is:**
  A **specific cognitive bias.**
- **Purpose (unintentional):**
  Maintain consistency with existing beliefs, expectations, or assumptions.
- **Nature:**
  Systematically **distorts information processing.**
- **Timing in cognition:**
  Acts mainly during **information selection and interpretation** (especially early, at SA Level 1).
  ↳ info processed too selectively
- **Behavior:**
  - Selects confirming evidence
  - Ignores or downplays contradictory information
  - Explains away inconsistencies

➡️ Confirmation bias is a **systematic error pattern.**

**4 Why confirmation bias is NOT "just another shortcut"**

| Heuristic | Confirmation Bias |
|---|---|
| Helps you **generate** a hypothesis | Forces you to **defend** a hypothesis |
| Happens **before** decision is fixed | Happens **after** decision is fixed |
| Keeps options open | Closes options |
| Efficient | Dangerous under uncertainty |

**5 One sentence that clears everything**

> **Heuristics help you recognize a situation; confirmation bias prevents you from re-evaluating it.**

# Naturalistic Decision Making

↳ how experienced people actually make decisions in the real world
→ not theory

- Decision making process in **experienced professionals** ("the experienced decision maker") differ from analytical target process
- Why: Decision making takes place in a "naturalistic setting": **complex, dynamic environment** with **high demands** on the decision maker
- Decision situations are highly complex, sometimes chaotic

## Recognition Primed Decision Making (RPD) by Domain Experts



- Describes how experts make **fast, effective decisions** in **complex situations** (e.g., fire brigade commanders) based on automatic, intuitive decision-making

→ correct situation assessment (situat. awareness)

- Most important: correct **situation analysis**
- Fast decision-making process due to **recognition** (mental models in long-term memory)
- **No conscious awareness of information processing:** Intuitive recognition of the situation and intuitive search for suitable options
- BUT: ability to find rationale and argue (meta-cognition improves decision-making)
- **Fast solution implementation**: No comparison of multiple options
- About **90% of all decisions** in practice follow this pattern (Klein, 1985).

→ little conscious reasoning during the decisions but experts can tell their reasoning afterwards

### Two Phases of Recognition-Primed Decision Making (RPD)

#### 1) Situation Assessment

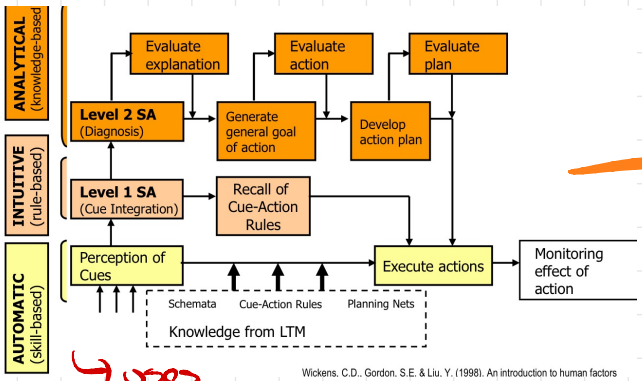
- The expert **recognises the situation** as familiar.
- Key goals and priorities are identified.
- Attention is focused only on **relevant cues.**
- An **initial action** is immediately suggested by experience.

👉 *This is mainly perception + pattern recognition from long-term memory.*

#### 2) Mental Simulation

- The expert **mentally "runs through"** the chosen action.
- Asks: *"Will this work? What happens next?"*
- If the outcome seems acceptable → **act immediately**.
- If not → **adjust or refine** the action.

👉 *Only one option is simulated, not multiple alternatives.*




↳ decision making limited
→ attention resource limited
→ working memory small
→ time pressure & workload restrict deep analysis




Wickens. C.D., Gordon. S.E. & Liu. Y. (1998). An introduction to human factors

↳ uses mainly this

### 1) Information Processing & Naturalistic Decision Making (first slide)

**Core message:**
Decision making can happen at **three different levels**, depending on time pressure, experience, and task complexity.

- **Automatic (skill-based)**
  → You perceive cues and act immediately.
  → No conscious thinking.
  *Example:* Typing a known PIN, flying a stabilized approach.
- **Intuitive (rule-based)**
  → You recognize a pattern and apply an *if–then* rule from experience.
  → Fast, low effort.
  *Example:* "If engine vibration + rising EGT → reduce thrust."
- **Analytical (knowledge-based)**
  → You diagnose, generate goals, plan actions, and evaluate options.
  → Slow, effortful, high working-memory demand.
  *Example:* Troubleshooting an unfamiliar system failure.

➡ **Naturalistic Decision Making (NDM)** mainly uses the **automatic + intuitive paths**, not full analysis.

## Why experts decide faster?

### 2) Why experts are faster (second slide)

**Core message:**
Experts decide fast **because of what is stored in long-term memory (LTM).**

Experts have:

- A **rich library of subtle cues** ("something feels off")
- Strong **pattern recognition**
- Ready-made **if–then action rules**
- Knowledge of **likely consequences** from experience

This allows them to:

- Focus only on **relevant information**
- Set priorities immediately
- Act without comparing many options
- Keep cognitive workload low

➡ They **recognize**, not calculate.

### Methods to Boost Decision Making (1/2):

**Challenging intuitive decision making**

This is a **structured, analytical decision process** used to slow down intuition and reduce bias.

### Methods to Boost Decision Making (2/2):

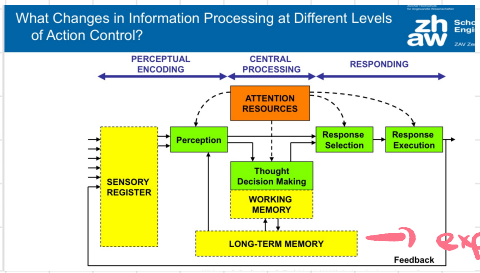
**Enhancing expertise** (Macrocognition)

- **Systematic decision process** = slows intuition to reduce bias
- **Macrocognition** = strengthens expert intuition in real-world conditions

# Learning to become an Expertise

9

## Skill Acquisition and Expertise




What changes in experts?

↳ with increasing skill and expertise, processing becomes less conscious & requires less attention

↳ minimal working memory involved

→ experts → here information is processed

→ fast, robust, efficient

## Skill Acquisition

↳ complex process → from basic understanding to high-level mastery → through practice, feedback & adaption through the passage of cognitive, associative & autonomous stage

| Knowledge-based | Rule-based | Skill-based | Rasmussen: |
|---|---|---|---|
| Intellectual level: analyses, plans | Perceptive-conceptual Level: flexible patterns of action | Sensumotoric level: automatisms | Hacker: Handlungs-regulations-ebenen |
| **Cognitive phase:** Instruct declaratives Knowledge for execution of action Training with feedback | **Associative phase:** Practice until error-free, correctly timed, Feedback from self-monitoring, release of cognitive resources | **Autonomous phase:** More practice to overlearn, little resources needed to control action, better time-sharing and stress resistance | *Fitts (1962) phases of skill acquisition* ***Perceptual-motor. skills*** |
| **Declarative knowledge representation:** Explicit rules to execute task | **Knowledge compilation** Development of proceduralized knowledge (tuning, discrimination, strengthening) | **Procedural knowledge:** Use of productions (if-then) | *Anderson (1982)* ***Cognitive skills*** |

**Cognitive:**
- you think consciously about every step
- you think about what to do
- high demand on attention
- use rules

**associative:**
- fewer errors
- feedback is used to improve
- less conscious effort than before
- rule based → if-then

**autonomous:**
- skill execution is automatic
- minimal attention required
- performance fast, robust → even under stress

↳ actions are automatic

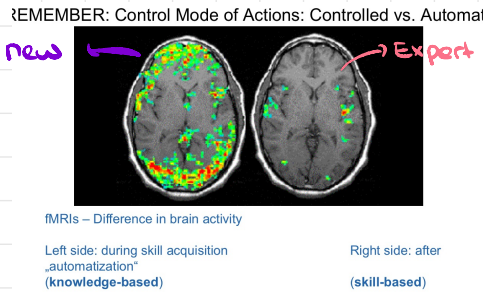
### From Beginner to Expert

- **Deliberate practice:**
  - Intentional practice (work on weak areas), not simply repeating a skill
  - Immediate feedback to identify errors and guide improvements
  - Breaking down of skills to automate correct execution
- Stronger and refined **mental representation**: model of how the skill should be executed
- Growth **mindset** and intrinsic **motivation** (personally meaningful and enjoyable)
- Contextual practice and **transfer**: practice in various contexts and conditions to improve adaptability and robustness of skill in real-world situations.
- **Spaced learning** sessions and rest: regular breaks and spaced practice sessions to enhance retention. Consolidation of learning takes place during resk periods/during sleep.

### Drill Sessions

- **Short** and focused sessions, including short breaks every 10 – 15 minutes. Longer rest periods (days/weeks) for complex or physically demanding skills.
  - ↳ short & focused
- **Frequency** over duration
- Duration depending on …
  - ↳ supports memory consolidation
  - Skill complexity:
    - Mastery of isolated **simple** skill: shorter drill sessions (5-10 min.) with hight repetition
    - Mastery of **complex** (compound) skills need more time (20 – 30 min.) and frequent breaks for mental processing
  - Level of proficiency:
    - **Beginners**: shorter, more frequent drills (5 – 10 min. per specific task) to build muscle memory and basic understanding
    - **Intermediate** lerners: refine skill and add complexity (15 – 20 min.)
    - **Advanced** learners: focus on improvements of details (15 – 20 min.), exploration, testing and drill

## Expert Performance




Experts notice the right cues immediately (even subtle)

↳ ▷ fast because recognise situation → not because they think longer

▷ uses little attention → they don't get overloaded

↳ ▷ do not need to generate or compare many options

▷ experts have stored if-then rules

▷ priorities set quickly

↳ recognise consequences immediately

## Becoming Expert

↳ someone who: consistently displays outstanding performance in his area

routine expertise: highly trained skills

adaptive expertise: flexible adaption to new problems

**Peculiarities of Experts** it seems they've overcome human limits → they work more efficiently

↳ they bypass: limited attention capacity, slow conscious processing

**How they do it**

- **Parallel processing:** many things are processed automatically, without conscious effort.
- **Vigilance corridor:** broad monitoring instead of narrow focus.
- **Intuition:** subtle cues are recognized instantly and trigger stored action patterns.
- **Reflection:** they adjust and improve their behavior over time.

# What is needed to become an expert ?

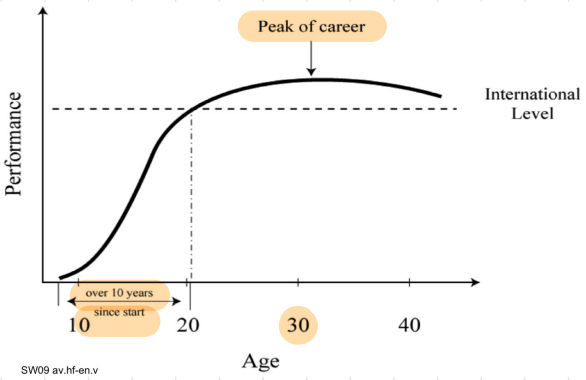
## What is needed to become an expert?

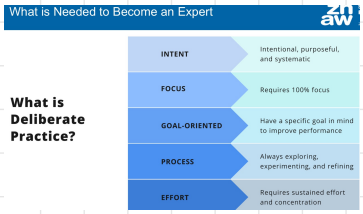
**Experts are not born — they are built through deliberate practice.**

- **Deliberate practice:** many years of focused, effortful training (not just repetition).
- **High concentration:** training targets specific weaknesses, not comfort.
- **Varied experience:** exposure to many different and difficult situations.
- **Feedback & correction:** errors are identified and fixed continuously.
- **Mentors/coaches:** guidance accelerates learning and avoids bad habits.

### What this leads to

- **Large pattern library:** experts recognize situations instantly.
- **Refined intuition:** intuition based on experience, not guessing.
- **Automatic skills:** fast, reliable actions with little mental effort.



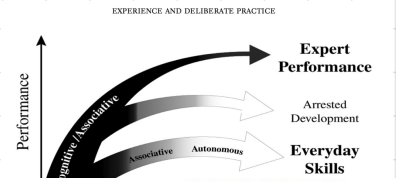





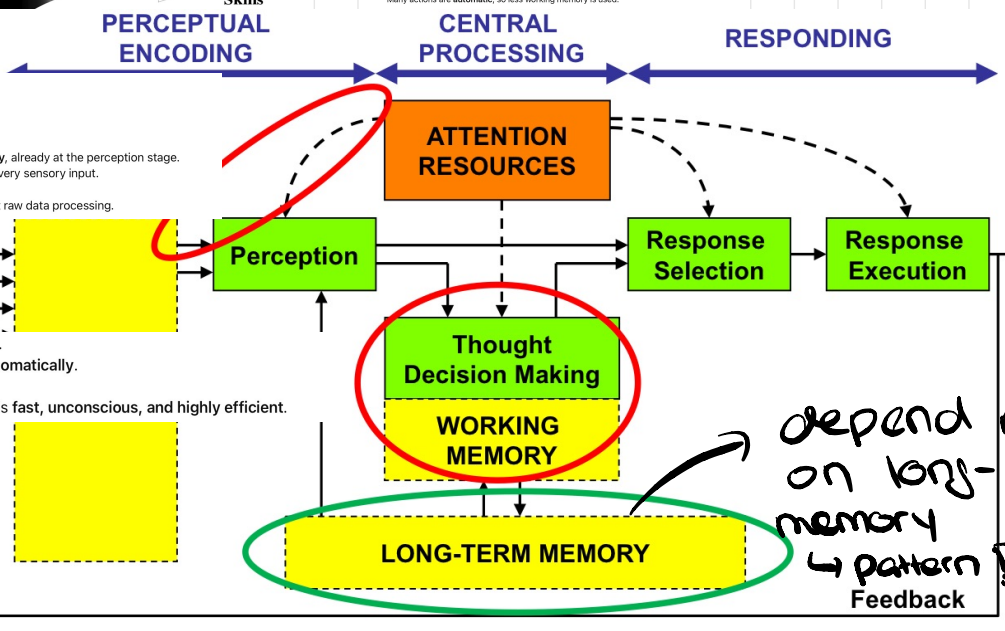


Habitual repetition:
- repeating same task again & again performance improves first → then reaches plateau
  ↳ you become automatic but stop improving

→ deliberate practice
practice with reflexion & feedback
↳ actively working on weakness
→ performance continues to increase over time




- **Comprehensive, domain-specific knowledge**
  Experts know a lot **about their specific field**, not just general facts.
- **Use of chunks**
  Experts group information into **meaningful patterns**, so they understand situations quickly.
- **Case-based knowledge organisation**
  Knowledge is stored as **experienced cases**, making it easy to see what applies to the current problem.
- **Deeper processing**
  Experts understand **why** something is a problem, not just **what** the problem is.
- **High proceduralisation**
  Many actions are **automatic**, so less working memory is used.




1. Red circle at Perception

**Your note:** experts bypass limits
**Meaning:**
Experts extract **meaningful cues very early**, already at the perception stage.
They do **not** need to consciously inspect every sensory input.

→ Perception is **guided by experience**, not raw data processing.

Experts do **not process all information**.
They process **the right information automatically**.

→ Selective attention **still exists**, but it is **fast, unconscious, and highly efficient**.

depend more on long-term memory
↳ pattern !

# Human Performance Modelling 10

Human Performace Modelling, Design for Human-Machine Interaction, Automation, Human-AI Teaming

## Definition of Human Performance Models (HP)

1→
- Human performance modeling (HPM) is a method of **quantifying human behavior, cognition, and processes**. It is a tool used by human factors researchers and practitioners for both the **analysis of human function** and for the **development of systems** designed for optimal user experience and interaction

2→
- Human performance models **predict** human behavior in a task, domain, or system regarding
  - The **products** of human performance (e.g., decision outcome)
  - The **process** of human performance (e.g., simulation of human decision process)
- Models of human performance provide a **systematic and computational understanding of the mechanisms** of human behavior quantifying complex relationships (Wu, 2018) unifying many scattered empirical findings.
- The ability to predict human behavior may prevent errors and accidents to improve system safety and efficiency.
- These models must be based upon and compared against empirical human-in-the-loop data (validation) to ensure that the human performance predictions are correct.

### Modelling Rasmussen SRK model

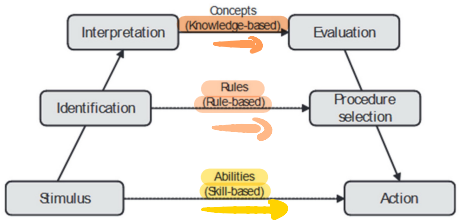
Human actions can fail at different levels:
- Skill based → (automatic actions go wrong)
- Rule based → wrong rule applied
- Knowledge based → wrong reasoning in novel situations

↳ model helps estimate how likely incorrect actions are depending on the level involved

↳ What must be defined for making a model

Decision Making Model: needs to specify …
- Initial state ↳ where humans start
- Goal state ↳ what humans want to achieve
- All possible intervening states (problem space)
- Path constraints ↳ all possible intermediate ↳ limits (workload) states
- State action Tree ↳ what actions are possible in each state
- Means-ends analysis ↳ how people choose actions

Criteria for design and evaluation of Human Performance Model:
- Represent relevant **mechanisms** of human performance → real human mechanism
- **Usefulness**: improve real-world system performance/safety/efficiency
- **Robustness** and **generality**: able to predict multiple experimental results without over- or under-fitting ↳ work across systems
- **Simplicity**: parsimonious rule ↳ be simple




## Challenges of HPM

↳ Complexity → models must simplify
- if model tries to include everything → becomes unstable
- if too simple → becomes unrealistic

↳ Probabilistic nature of human behaviour → humans don't always react the same

↳ Internal-external validity trade-off → the more control applied (very specific) → the less representative the model is for operat. environm.

Anthropometric and biomechanical models help predict how the human body moves & bears load → so systems can be designed to be safe, efficient
- Anthropometric: body dimensions, reach distances, body sizes
- biomechanical: movement, lifting mechanics, muscle forces
- With the help of

With the help of Cognitive process human first notice & focus on information → but attention capacity are limited → when we must choose between many answers → decisions take longer → brain needs processing → this model helps how people think, remember, stay aware of situat

### Human Performance Modelling (HPM) in Aviation

zh aw School of Engineering ZAV Zentrum für Aviatik

- "The aviation community is continuously striving to increase the efficiency and safety of the entire aviation system, which includes **human operators** (e.g., commercial airline pilots, general aviation pilots, and air traffic controllers), **technology** (i.e., hardware, software, automation, displays, and controls), and the **interactions among human operators and technology**.

  Addressing these **complicated system interactions** requires research toward the design and development of new system concepts; investigation of procedural, training, and communication issues; and the design and evaluation of avionics, equipment, and interfaces" (Foyle & Hooey, 2007).

- Despite these advances, however, there is still a gap between even the most advanced models and engineering practice (Byrne et al., 2008).

This NASA project studied how **humans behave and make errors** when aviation systems, procedures, or requirements change. The goal was to **predict human error early**, so systems can be designed safer before they are used in real operations.

NASA tested **several human performance models** (like ACT-R and situation-awareness models) on the **same aviation problems** to see how well they explain and predict pilot behavior.

They applied these models to **real and future aviation cases**, such as:
- **Airport taxi operations** (to understand navigation errors on the ground)
- **Synthetic Vision Systems (SVS)** (to evaluate new cockpit concepts before deployment)

Overall, the project showed that **Human Performance Modelling is useful for system design**, helping engineers improve safety, training, and operational procedures before accidents happen.

NASA followed **two parallel development tracks** to prevent aviation accidents using Human Performance Modelling (HPM).

**Top track – Predictive models (what might go wrong):**
NASA used different human performance models to **predict where** and **why pilots make errors**, starting with taxiway errors and later extending to approach and landing with augmented displays. The models were tested across **many scenarios** and finally **verified and validated** to check if their predictions were reliable.

**Bottom track – Prescriptive models (what to do about it):**
Here, NASA focused on **engineering solutions**: analyzing real flight data, identifying **error mechanisms**, and running **simulations with virtual pilot agents (CATS)** to test how design changes could reduce errors.

**Big picture:**
One track predicts **human errors**, the other designs **solutions to prevent them**. Together, they support **system-wide accident prevention**.

# Design for Human-Machine Interaction

Goal: Design for Situation Awareness (SA)

SA 1: Perception → notice relevant elements from environm.

SA 2: Comprehension → understanding what these elements mean together

SA 3: Projection → anticipating how situation will develop in near future

SA → essential for correct decision-making  no SA → wrong understanding → wrong actions

## General Design Requirements:

**User-centered perspective** - A user-centered perspective involves focusing on the needs and requirements of the end user throughout the design, acquisition, or development process.

**Consistency** - Consistent means adhering to the same principles with minimal variation.
↳ similar things should look & work the same everywhere

**Modular** - To be modular means to be designed with standardized or uniform components.
↳ easier to understand

**Standardization** - Standardization refers to common user-interface features across multiple applications.

### 1. Design requirements for target search

This is about how easily a person can **find the right information** on a display.

- If there is **too much information** or it is **poorly clustered**, the target is harder to find and takes longer.
- The **target must clearly stand out** from the background (colour, size, shape, contrast).
- Because attention is **selective**, users must actively scan the display — design should therefore **reduce unnecessary scanning**.

Key limitation:
➡️ **Sharp vision exists only in the fovea** (about 2°). Everything else is less clear.
➡️ Every eye movement and attention switch costs **time and mental effort**.

# Automation

↳ execution of a function by a machine which previously executed by a human

↳ primary purpose: use it where human show weaknesses

### Tasks of the Pilot in an Automated System

- **Planning** what automation should do
- **Programming** of the system
- **Monitoring** of the execution by the machine
- **Communication** (cockpit crew, ATC)
- **Intervention,** if indicated (automation error)
- **Deciding, problem solving**
- **Reflecting**, or learning from experience and building an appropriate mental model of automation

### 2. Phase Model of Information Processing & Levels of Automation

This model shows **where automation can be applied along the human decision chain.**

Human information processing happens in four phases:

1. **Information recording (acquisition)**
   → Sensors collect data
   *Examples:* radar, cameras, sensors, HUD
2. **Information analysis**
   → System detects problems or patterns
   *Examples:* alarms, TCAS, warning systems
3. **Decision making**
   → System suggests or selects actions
   *Examples:* FMS, ECAM/EICAS, runway status lights
4. **Execution of action**
   → System physically acts
   *Examples:* autopilot, autothrottle, fly-by-wire

Key idea: down
- The **further** you automate, the **less the human is involved**.
- Higher automation increases efficiency but **raises risks** if the human is not aware or prepared to intervene.

### 3. Ways of information presentation: Analog vs Digital

**Analog instruments**
- Pilot must **scan many instruments**
- Very good for seeing **trends and changes quickly**
- Exact numbers are less obvious
- High maintenance effort

**Digital displays**
- Information is **integrated and consolidated** (less scanning)
- Exact values are clear, but **digits take longer to read**
- Allows **alerts, warnings, and system integration**
- Higher initial cost, lower long-term workload

Design takeaway:
➡️ Analog = good for **trend perception**
➡️ Digital = good for **integration and situation awareness**
➡️ Modern cockpits combine both strengths.

## Adaptable vs. Adaptive Automation

Adaptable: user decides when & how long automation is used → autopilot

Adaptive: system changes automation level automatically

## Role Shift of the Human

Systems with no automation:
- Flight duty tasks

↳ human perform everything

Automated systems:
- System management
- Monitoring

→ human's role shift (selecting modes) (checking if automation behaves as expected)

Human-centered design

because of this role change ←

**Human-Machine Interaction**

critical challenge becomes interaction not control

Mental model to understand the system to maintain SA

### 2. Mental models

A *mental model* is the operator's internal understanding of:

- what the system is doing,
- why it is doing it,
- what it will do next.

⚠️ When the system becomes too complex, the mental model becomes **incomplete or wrong**.

# Technical Issues

**Technical Issues with Automation (1/2):**
As systems become more automated, they also become more complex, with many subsystems, operating modes, and tightly coupled sensor–decision–actuator chains. This makes it difficult for operators to fully understand how the system works at any given moment. To operate safely, humans rely on *mental models*—internal explanations of what the system is doing and why—but increasing complexity often leads to incomplete or incorrect mental models. This results in uncertainty, unexpected system behavior, and even disagreement within crews. A key challenge is therefore deciding how much system knowledge operators need and how that knowledge should be presented without overwhelming them.

**Technical Issues with Automation (2/2):**
Highly reliable automation can reduce active human involvement, leading to complacency, reduced monitoring, and distraction. When systems run smoothly for long periods, operators may stop paying close attention and become "out of the loop," which makes it harder to detect or respond to failures quickly. At the same time, human attention is limited: people cannot continuously monitor complex systems with many modes and states. This creates a fundamental challenge for human–automation teaming—designing systems that support human attention, maintain situation awareness, and adapt to the human's current state, workload, and intentions rather than assuming constant, perfect monitoring.

# Impact of Automation on Human Operators

**(1/3) Loss of Situation Awareness** Awareness - Processing - Anticipation
Automation can reduce situation awareness because humans are no longer continuously engaged in perceiving, interpreting, and anticipating system behavior. When operators are taken out of the active control loop, their mental model of the system degrades. To maintain situation awareness, system functions must be transparent and understandable, and humans must remain cognitively involved rather than only supervising passively. High automation reliability can further lead to complacency and reduced monitoring.

**(2/3) Insufficient or Excessive Confidence in Automation**
Trust in automation is dynamic and mainly driven by perceived system reliability. If automation is unreliable (e.g. frequent false alarms), operators lose trust and underuse it (disuse). If automation appears highly reliable, operators may overtrust it, stop monitoring, and misuse it, leading to reduced vigilance. A third issue is abuse of automation, where designers or managers introduce automation without considering human limitations and performance consequences.

**(3/3) Loss of Manual Skills (Deskilling)**
Automation shifts the human role from manual control to planning, monitoring, decision-making, and intervention in rare or abnormal situations. Because operators spend less time manually controlling the system—especially during long, routine operations—manual skills degrade over time. This deskilling is reinforced by insufficient training opportunities and can become critical when manual intervention is suddenly required in unexpected situations.