Experimental Ergonomics

Applications of empirical methods to explore and better understand interactions among humans and other elements of a system, in order to optimize human well-being and overall system performance

Educational Material

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- Design, Computation, Product Development & Manufacturing
- Bioengineering

Experimental Ergonomics*

Content

*)
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1. Definition, Knowledge, System Model

1.1 Definition

Ancient Greek terms: ἔργον & νόμος.
érgon - work & nómos - law (Jastrzębowski 1857).

Synonyms: Ergonomics, Human Factors, Work Science

Ergonomics is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance (IEA 2016, www.iea.cc).

Major objectives of Ergonomics:
a) To enhance the effectiveness and efficiency with which work and other activities are carried out.
b) To enhance certain desirable human values, including improved safety, reduced fatigue and stress, increased comfort, greater user acceptance, increased job satisfaction, and improved quality of live.

Human factors engineering
Human factors engineering is the application of knowledge about human capabilities (physical, sensory, emotional, and intellectual) and limitations to the design and development of tools, devices, systems, environments, and organizations.

Objectives of applied ergonomics:

human well-being	- Safety - Health - Satisfaction - Comfort - Joy
overall system performance	- Effectiveness, - Efficiency - Reliability

ANSI/AAMI HE75:(R)2013
American National Standard,
Association for the Advancement of Medical Instrumentation
Human Factors Engineering - Design of medical devices.

Sanders, M.S. & McCormick, E.J. (1993).
Human Factors in Engineering and Design. New York: McGraw-Hill.

Jastrzębowski, W. (1857).
Rys ergonomji czyli nauki o pracy, opartej na prawdach poczerpniętych z Nauki Przyrody
(The Outline of Ergonomics, i.e. Science of Work, Based on the Truths Taken from the Natural Science).
Przyroda i Przemysl (Nature and Industry), 29.

1.2 Areas of Knowledge

Basic education (areas A-J of knowledge) + Advanced level of Knowledge (studies).
→ Requirements for registration of European Ergonomists (www.eurerg.org)

A Principles of Ergonomics
Definitions, Aims, Approach, Systems, User-centred design, Ergonomics practice.

B Populations and general human characteristics
Anatomy, Physiology and Biomechanics, Work physiology, Cognition, Perception, Circadian Rhythm, Age and gender differences, Disabilities.

C Design of technical systems
Design for assembly / maintenance, Production system design, Architectural design.

D Research, evaluation and investigative techniques
Experimental design and evaluation, Survey methods, Qualitative and quantitative measurements, Descriptive and inferential statistics, Information systems / technology.

E Professional issues
Ethics, Standards, Laws, Reporting, Client relationships, Teaching, Instructing.

F Ergonomics: Activity and / or Work Analysis
Task and system analysis and evaluation, Methods and instruments for measuring human activity, Methods of activity analysis.

G Ergonomic Interventions
Methods and design of intervention projects, Evaluation of ergonomics projects

H Ergonomics: physiological and physical aspects
Workplace layout and design, Anthropometry, Posture, Repetitive workloads, Manual Handling / Heavy loads, Work-rest cycles, Methods and instruments for measuring physical environment, Climatic and thermal factors, Lighting, Sound, Vibration and acceleration, Pressure, Air quality, Electromagnetic radiation.

I Ergonomics: psychological and cognitive aspects
Human information processing, Human reliability, Allocation of functions, Information design, Controls and displays, Human machine interaction, Fatigue / workload / vigilance, Emotional aspects of design.

J Ergonomics: social and organisational aspects
Systems theory, Organisation design, Work organisation / work flow / logistics / work load, Group vs. individual work, Job allocation and design, Participation and autonomy, Organisation culture, Management of change(s), Motivation and attitude change.

Advanced level of knowledge: Studies in ergonomics:
- Architecture, Engineering / Systems Engineering, Industrial Design.
- Epidemiology, Health, Safety and Well-Being at work, Psychology, Sociology.
- Information Technology / Computer science, Statistics.
- Occupational Hygiene, Occupational Medicine, Occupational Therapy, Physiotherapy.

1.3 System Model - human at work system

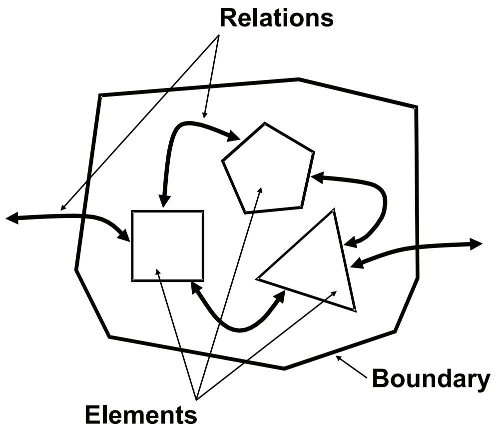


Fig. 1 System structure.

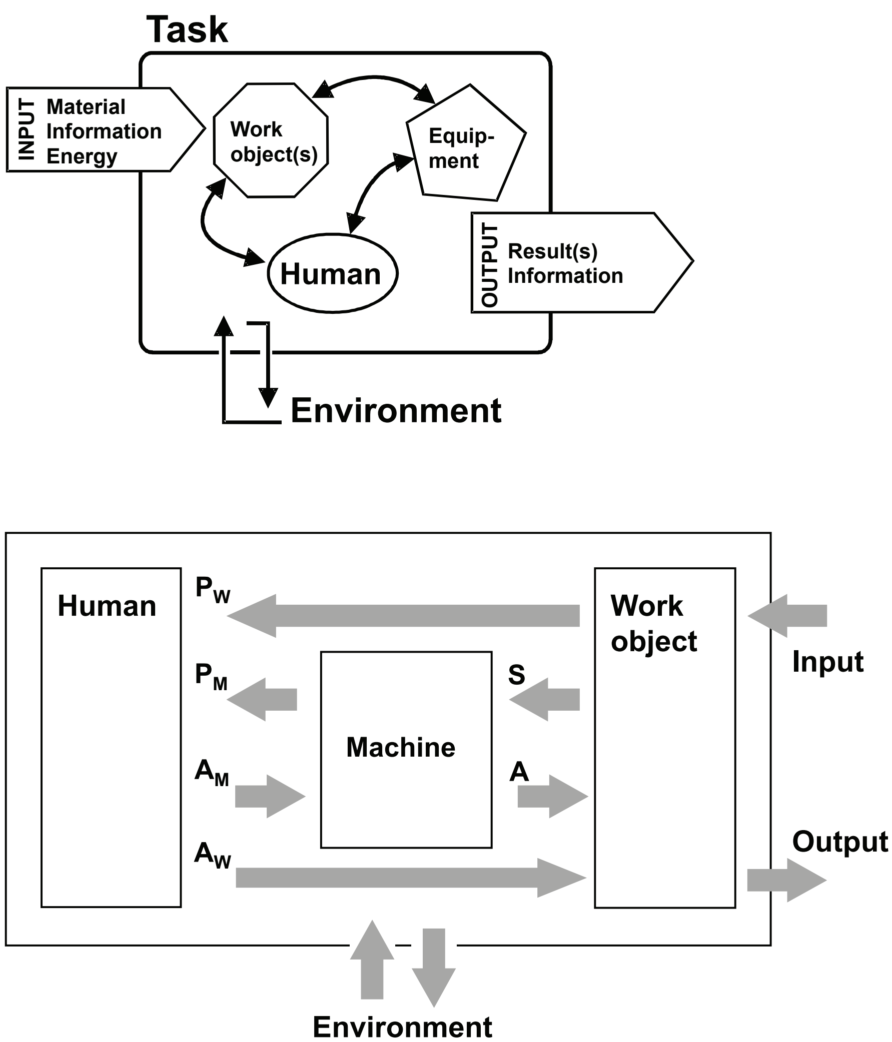


Fig. 2 Human at work systems. Environment: spatial (work space), physical, organizational, social, legal, cultural.

2. Concepts in Ergonomics

→ ISO 26800:2011 Ergonomics - General approach, principles and concepts.

2.1 System Concept - Systems Ergonomics

The application of systems theory and analysis to the interaction of human and machine.
Machine: Processing of input to output, transfer functions, differential equations.
Human: Sensory, cognitive and motor processing.

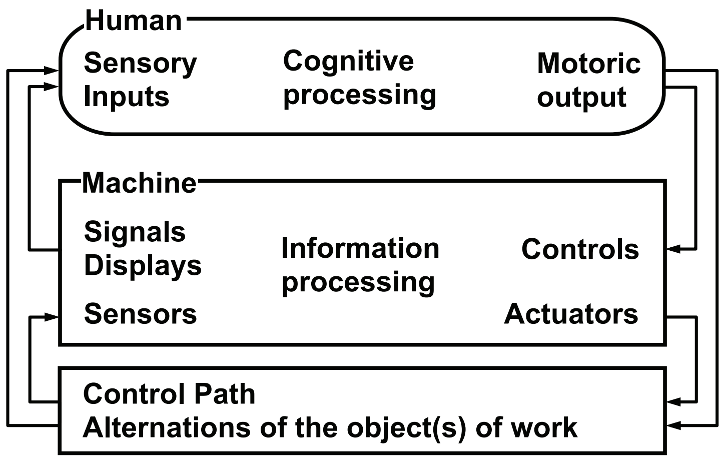


Fig. 3 Human-machine system.

2.2 Stress and Strain Concept or Load-Effect Concept

„Stresses do not only depend on the workload and the heaviness and the difficulties of the task and its duration, but also on the work environment with its physical and chemical components (i.e. climate, noise, lighting, etc.) and its social components [...] The theory of the stress-strain concept indicates that the strain cannot be determined wholly by the consideration of the specific stress. Strain is also dependent upon the individual characteristics, abilities, skills and needs of the working person.“ (Rohmert 1986, p.166-168).

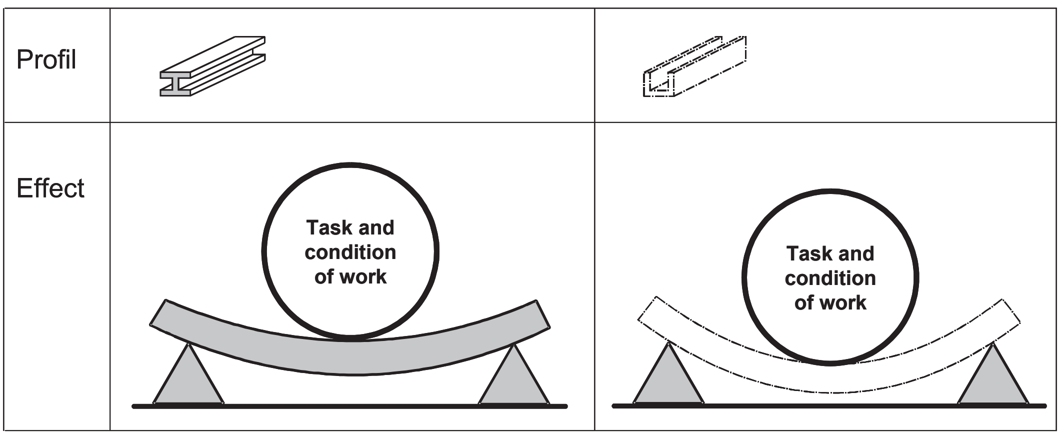


Fig. 4 Concept of stress and strain by analogy with mechanics.

Rohmert, W. (1986).
Ergonomics: concept of work, stress and strain.
International Review of Applied Psychology, 35, 159-181.

2.3 Concept of Usability

→ISO 9241-11:2016 Ergonomics of human-system interaction - Part 11: Usability: Definitions and concepts.

Usability: the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context.

Note:

- Satisfaction is positive attitudes, emotions and/or comfort resulting from use of a system, product or service.

- Usability relates to the outcome of interacting with a product, system or service. Usability is not an attribute of a product, although appropriate product attributes can contribute to the product being usable in a particular context of use.

- European standards, relevance for medical products.
  → DIN EN 60601-1-6:2016. Medical electrical equipment - General requirements for basic safety and essential performance - Collateral standard: Usability.

2.4 Concept of Accessibility

Accessibility: The extent to which products, systems, services, environments and facilities can be used by people from a population with the widest range of characteristics and capabilities to achieve a specified goal in a specified context of use. Context of use includes direct use or use supported by assistive technologies.

The aim in designing for accessibility is to widen the target population, thus making products, systems, services, environments and facilities more accessible to more people.

Note:

- Accessibility vs. barrier free accessibility for people with disabilities.

- Terminology:
  Accessible design
  Barrier-free design
  Universal Design
  Inclusive Design
  Design for All

European Committee for Standardization (CEN)
European Committee for Electrotechnical Standardization (CENELEC)
→ CEN-CENELEC (2014). Guide 6, Guide for addressing accessibility in standards.
→ DIN (2002). Fachbericht 124, Barrierefreie Produkte (Technical Report 124 - Products in Design for All).

3. Design Principles

1 - Safety and Health
2 - Human and Task Suitability
3 - Simplicity and Clarity
4 - Guidance
5 - Transparency and Self-descriptiveness
6 - Consistency
7 - Compatibility

Safety and Health
The design of work systems or products should protect workers or users in their employment from risks resulting from factors adverse to health, and should promote and maintain the highest degree of physical, mental and social well-being.
→ ILO/WHO Committee on Occupational Health, http://www.ilo.org/safework

Human and Task Suitability
Systems or products are designed appropriate and compatible to the users' anthropometry, physiology, and psychology, and designed suitable to the users' tasks or work processes.

Simplicity and Clarity
The use of work place, equipment or products should be as simple as possible and without ambiguity. Complexity should mask through simple interfaces or progressive disclosure.

Guidance
The system and its elements should support orientation, learning and control through feed forward (indicators, signs, labels, instructions) and feed back in suitable modalities.

Transparency and Self-descriptiveness
The system should be designed transparent to its users, i.e. they can develop or apply an adequate inner representation or mental model about how the system supports their tasks. Thus the design should be self-descriptively communicate meanings of its elements to support the user´s exploration and ascertainment of the system.

Consistency
A system should look, act, and operate the same throughout. Same actions should always yield same results. Different work places or equipment for the same task should have the same structural and functional layout, i.e. should allow performing the same work procedure.

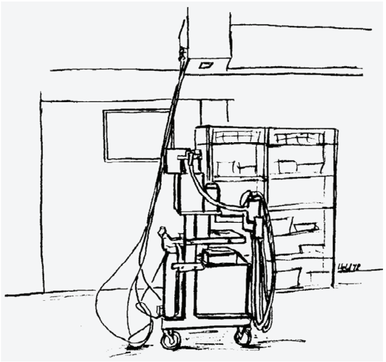
Compatibility
Things should work as they expected to work. Stimuli and responses should be in relation to human expectations. Types: conceptual (associations, mental model), movement (controls-displays), spatial (layout), modality (stimulus-response modality combinations). → Sanders, M.S. and McCormick, E.J. (1992). Human Factors in Engineering and Design. New York: McGraw-Hill, p. 58-59.

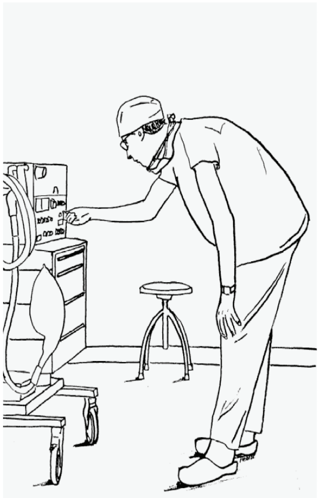
Note: principles can semantically overlap, trade-offs between principles can be necessary.

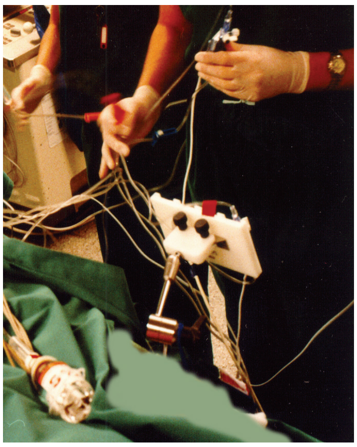
ISO 6385:2014.
Ergonomic principles in the design of work systems.

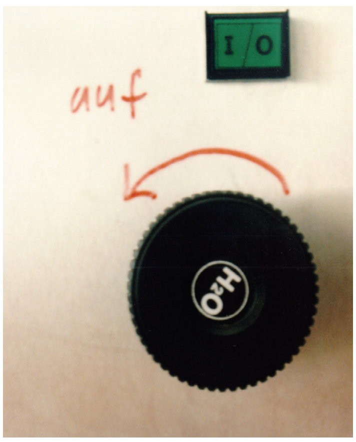
ISO 10075-2:2000.
Ergonomic principles related to mental workload - Part 2: Design principles.

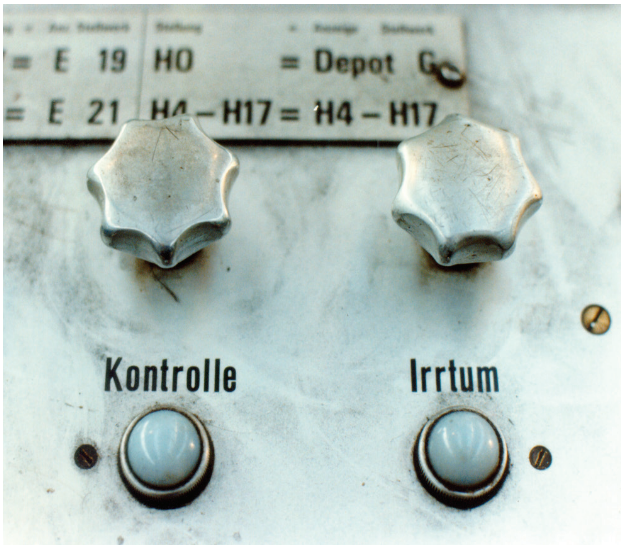
Discussion of design principles







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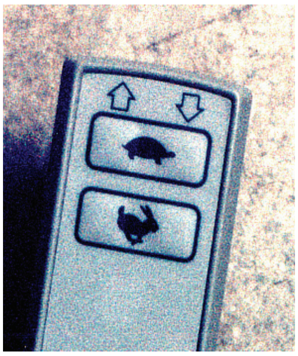

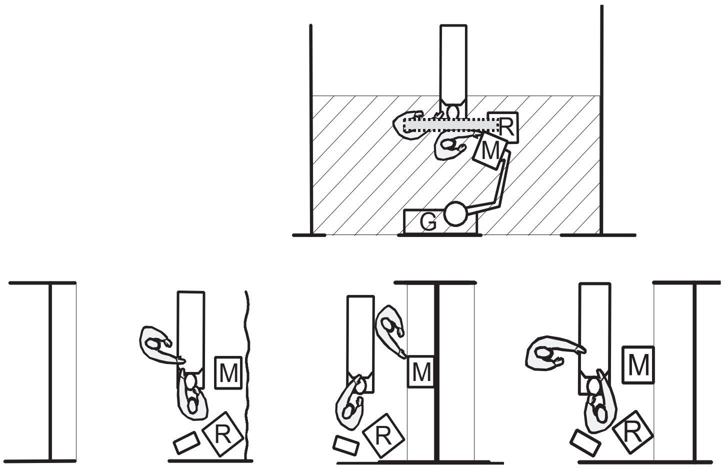
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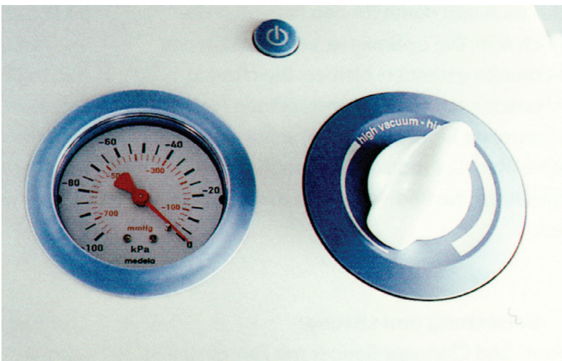
high vacuum
-60
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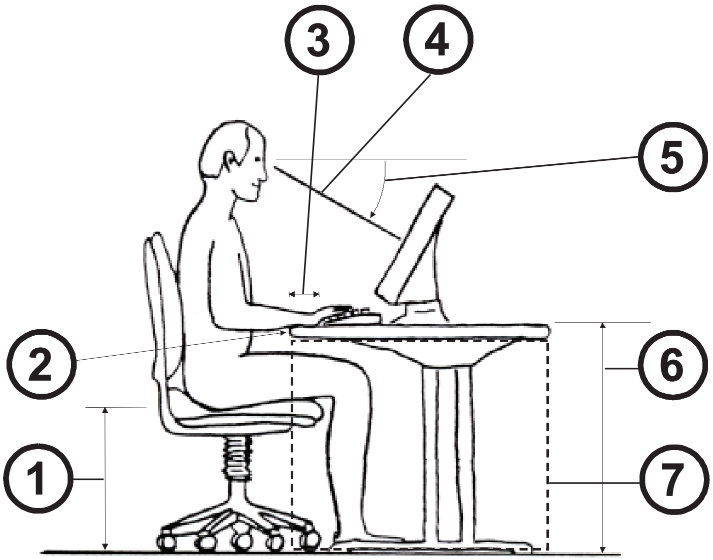
-80
-20
-100
mmHg
kPa
medela

4. Workplace design

4.1 Computer Terminal Workstations - Video Display Units (VDUs)



(1) Chair height

(2) Edge of table

(3) Wrist rest

(4) Viewing distance

(5) Viewing angle

(6) Table height

(7) Leg room

4.2 Anthropometrics

DIN 33402-2:2005	Ergonomie. Körpermaße des Menschen. Teil 2: Werte. (Ergonomics. Human body dimensions. Part 2: Values).
ISO 7250-2:2013	Summaries of body measurements from national populations.

Tilley, A.R. (2002). The Measure of Man and Woman. New Jersey: Wiley.
Pheasant, S. (2002). Bodyspace. London: Taylor & Francis.
CDC (2012). Anthropometric Reference Data for Children and Adults: United States, 2007–2010, Centers for Disease Control and Prevention.
Morlock et al. (2014). Kopfschutzsysteme. Hohenstein: IGF 16976N.

CDC Growth Charts www.cdc.gov/growthcharts/
WHO Growth Charts www.who.int/childgrowth/standards/en/
Lueder, R. and Berg Rice, V.J. (2008). Ergonomics for Children. Boca Raton: CRC.

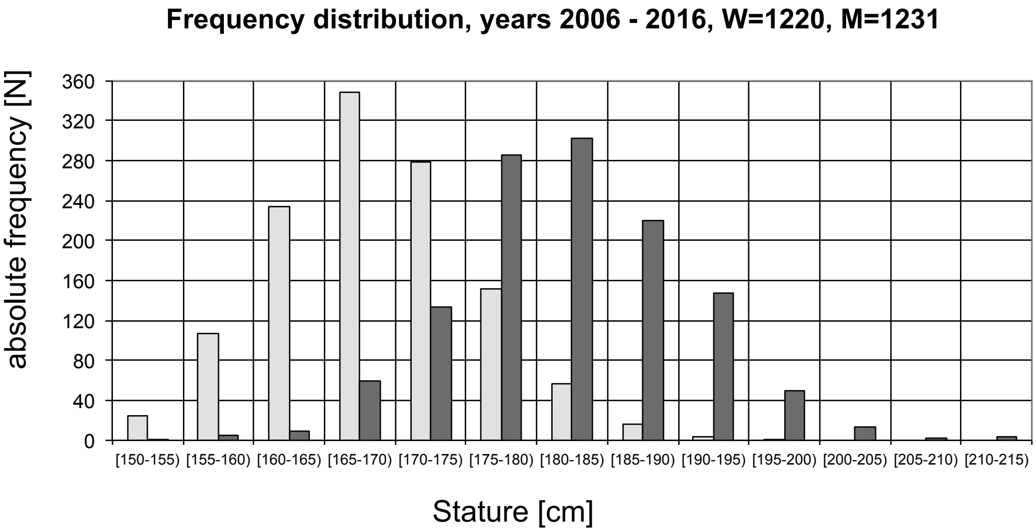


Fig. 5 Frequency distribution for the stature of women and man, adults, age ~ 18-25. Data from a questionnaire survey in Germany.

Tab. 1 Percentiles in comparison of stature in [mm], numbers in italics are interpolated.

	Survey 2006-16 ~ 18-25		DIN 33402:2005 18-25		DIN 33402:2005 18-65		DIN 33402:1978 16-60		Tilley 2002 USA adults	
%ile	W	M	W	M	W	M	W	M	W	M
1.	1530	1633							1476	1590
5.	1570	1690	1560	1685	1533	1650	1510	1629	*1520*	*1638*
50.	1680	1800	1660	1790	1625	1750	1619	1733	1626	1755
95.	1800	1940	1760	1910	1720	1855	1725	1841	*1732*	*1873*
99.	1860	2000							1774	1920

Body templates - Somatographics

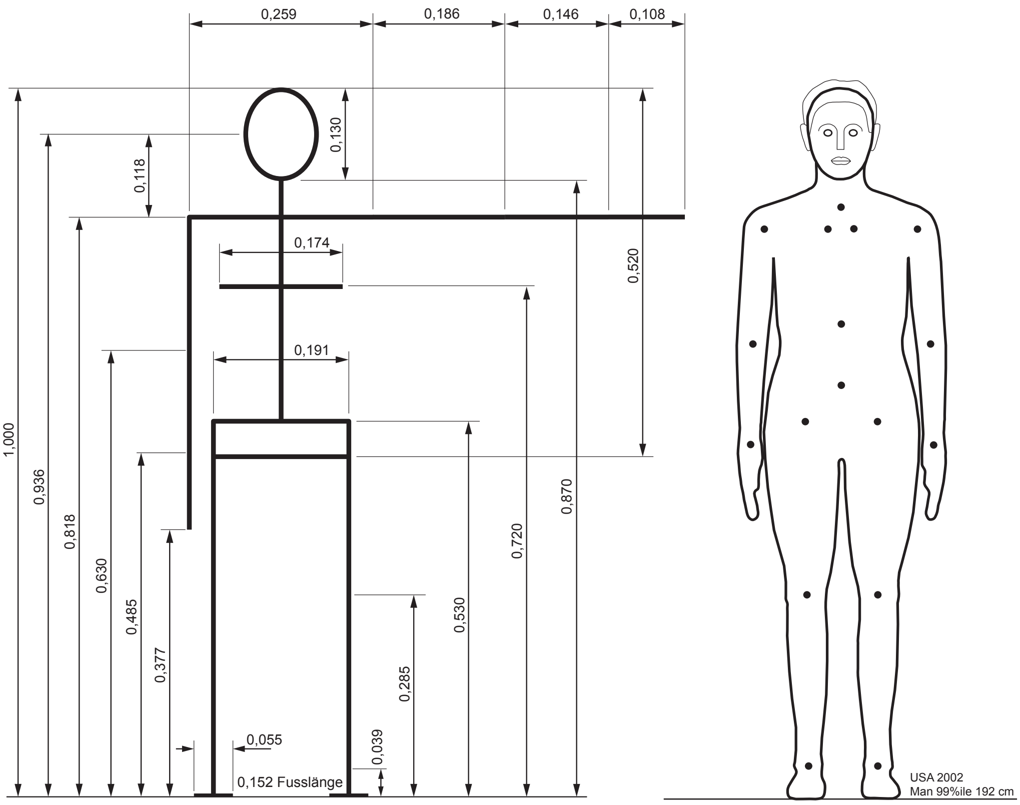


Fig. 6 Body segments and template.
→ Drillis, R et al. (1966). Body segments parameters.
Report 1163-03, Departement of Health, Education and Welfare, New York.
→ Tilley, A.R. (2002). The Measure of Man and Woman. New Jersey: Wiley.

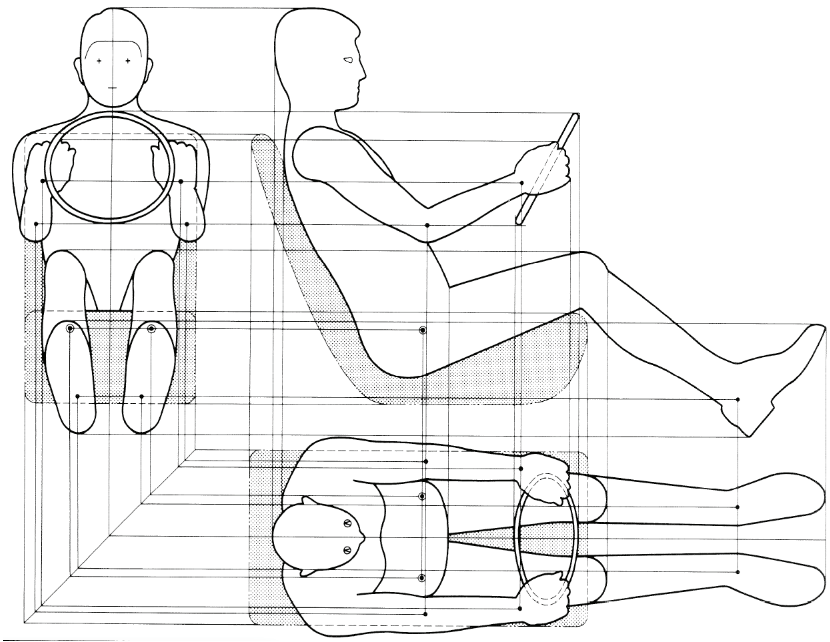
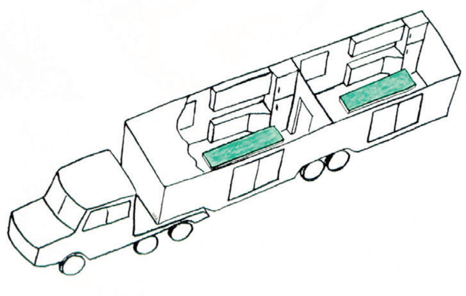
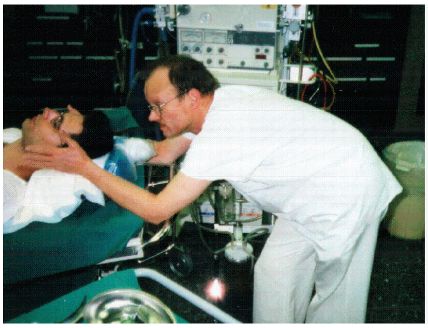


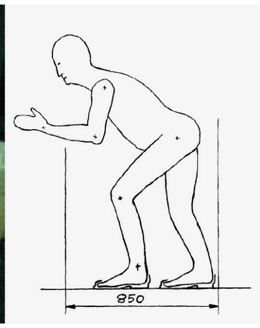
Fig. 7 Applied body templates.
→ DIN 33408-1:2008 Körperumriss-Schablone - Teil 1: Für Sitzplätze
(Body templates - Part 1: For seats of all kinds).

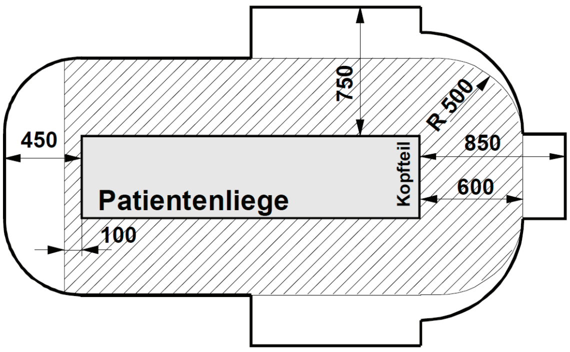
Case study

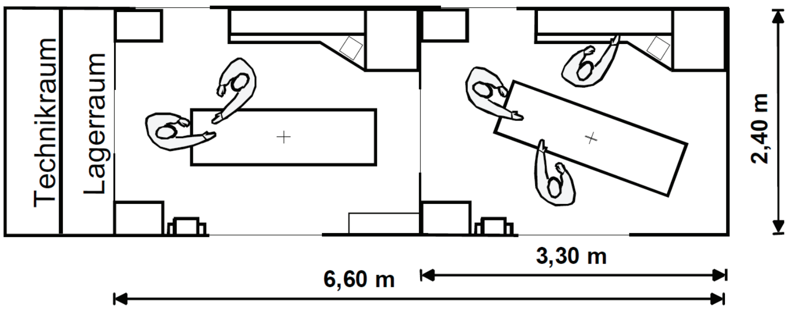
Airport Zurich Fire Brigade and Rescue Service











5. Information Transfer - Interface Design

5.2 Visual Perception

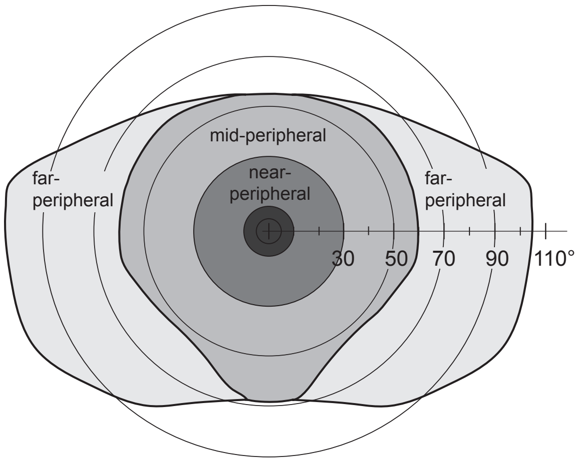


Fig. 8 Central and peripheral zones of bi- and monocular visual field in degrees deviation from the point of fixation. → Boyce, P.R. (2003). Human Factors in Lighting. Tayor & Francis.

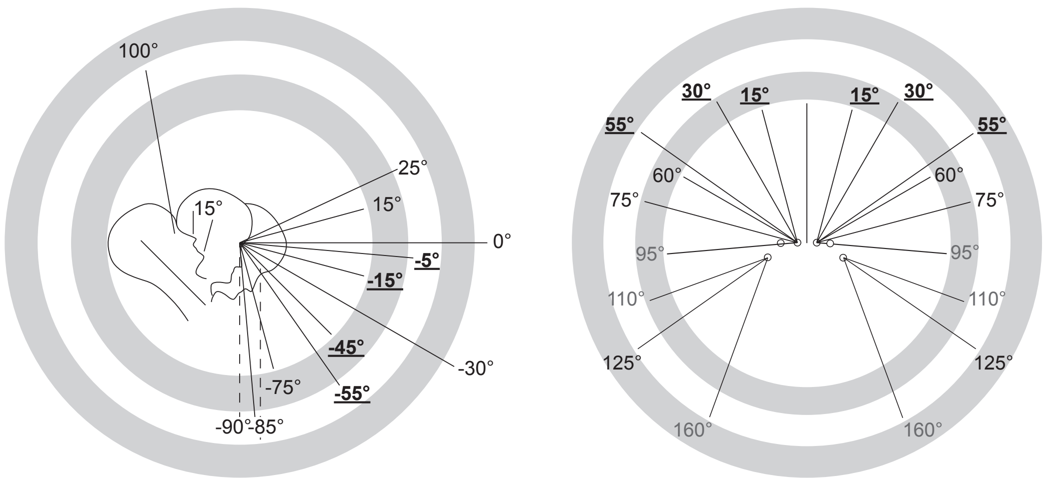


Fig. 9 Visual field for fixation, eye movement, head and eye movement (bold: optimal). → Schmidtke, H. (Eds.) (1989). Handbuch der Ergonomie. Koblenz.

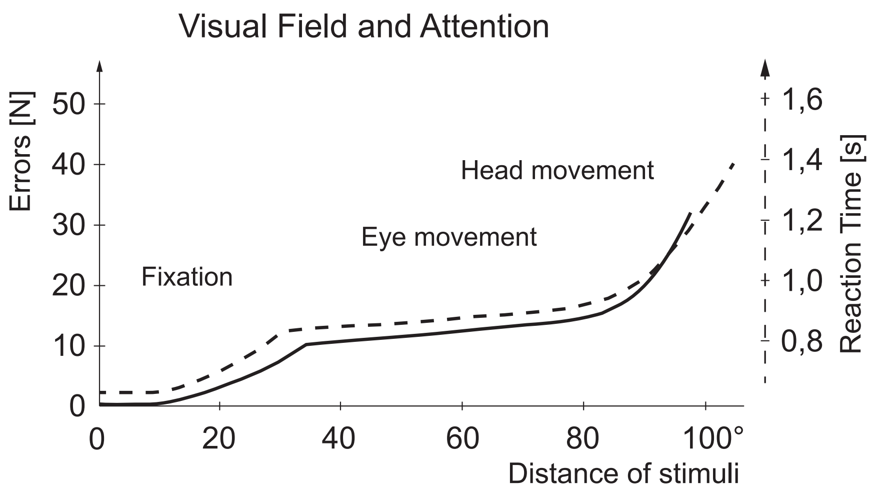


Fig. 10 Visual field and attention. → Krueger, H. (2000). Lecture in Ergonomics, ETH Zurich.

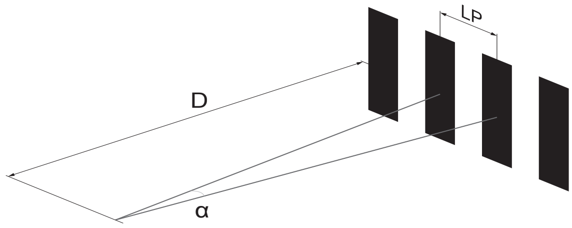


Fig. 11 Resolving pair of lines (LP), viewing distance (D) and visual angle (α).

Tab. 2 Visual acuity (α, Visus), viewing distances (D) and related resolution (LP/mm, ppi).

	Visus	D = 250 mm		D = 400 mm		D = 600 mm	
α [arc min]	(1'/ α)	[LP/mm]	[ppi]	[LP/mm]	[ppi]	[LP/mm]	[ppi]
2,0	0,5	6,9	349	4,3	218	2,9	146
1,5	0,7	9,2	467	5,7	290	3,8	193
1,0	1,0	13,8	701	8,6	437	5,7	290
0,5	2,0	27,5	1397	17,2	874	11,5	584

Fig. 12 Font metrics: Cap-height, H-height, x-height (Mittellänge).

Tab. 3 Minimum heights for reading text, visus ≥ 0,7.
→ Table entries: DIN 1450:2013. Schriften - Leserlichkeit (Lettering - Legibility).

	Lesetext (books, journals, ...) α [arc min] ≥ 13			Konsultationstext (Indices, footnotes, ...) α [arc min] ≥ 10		
D [mm]	x-height [mm]	H-height [mm]	Font height ≈ [pt]	x-height [mm]	H-height [mm]	Font height ≈ [pt]
400	1,5	3,5	9	1,5	2,75	7

Tab. 4 Display character height (cap-height), rounded to modul 0,25.

	Character height (cap-height) [mm]			
D [mm]	20 ≤ α [arc min] ≤ 22	18 ≤ α [arc min] ≤ 20	α [arc min] = 16	α [arc min] = 11
250	1,45 - 1,60	1,30 - 1,45	1,15	0,80
600	3,50 - 3,85	3,15 - 3,50	2,80	1,95
800	4,65 - 5,15	4,20 - 4,65	3,75	2,55
1000	5,85 - 6,40	5,25 - 5,85	4,65	3,20

Recommendations desktop computer display:
ISO 9241-303:2012, α [arc min]: 20 - 22, minimum α [arc min] = 16.
ISO 11064-4:2013 Ergonomic design of control centres, α [arc min] = 15.
Grandjean, E. (1988). Fitting the task to the man. α [arc min]: 16 - 25.
Olivetti (1981). Ergonomie und Olivetti, α [arc min]: 18 - 20.

5.2 Interface Guidelines

Tab. 5 Human-Computer Interaction, Interface Guidelines.

	Galitz, W.O. (2002)	ISO 9241-110:2006	macOS (2016)
1	Aesthetically Pleasing	Suitability for the task	Mental Model
2	Clarity	Self-descriptiveness	Metaphors
3	Compatibility	Conform with user expectations	Explicit & Implicit Actions
4	Comprehensibility	Suitability for learning	Direct Manipulation
5	Configurability	Controllability	User Control
6	Consistency	Error tolerance	Feedback & Communication
7	Familiarity	Suitability for individualization	Consistency
8	Flexibility		Forgiveness
9	Forgiveness		Aesthetic Integrity
10	Predictability		
11	Recovery		
12	Responsiveness		
13	Simplicity		
14	Transparency		
15	Trade-Offs		

→ Galitz, W.O. (2002). The Essential Guide to User Interface Design. New York: Wiley.
→ ISO 9241-110:2006. Ergonomics of human-system interaction - part 110: Dialogue principles.
→ https://developer.apple.com/ […] OSXHIGuidelines/DesignPrinciples.html.

Tab. 6 History of Human Interface Guideline, Apple, Computer, Inc.

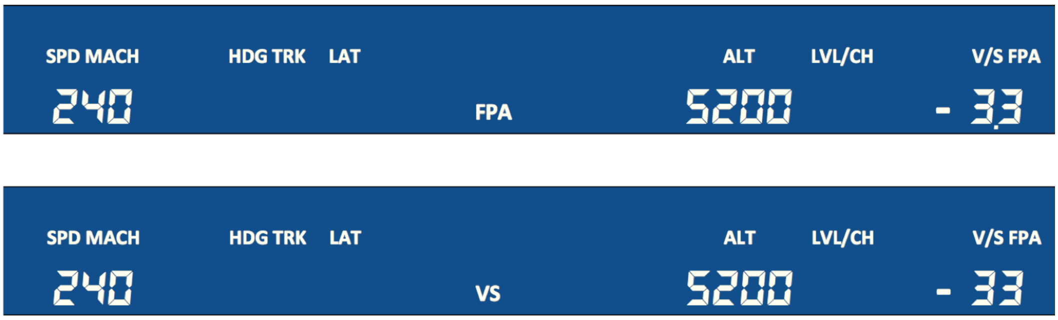
	Macintosh (1995)	Apple (2005)	macOS (2016)
1	Metaphors	Metaphors	Mental Model
2	Direct Manipulation	Reflect User´s Mental Model	Metaphors
3	See-and-Point	Explicit & Implicit Actions	Explicit & Implicit Actions
4	Consistency	Direct Manipulation	Direct Manipulation
5	WYSIWYG	User Control	User Control
6	User Control	Feedback & Communication	Feedback & Communication
7	Feedback and Dialog	Consistency	Consistency
8	Forgiveness	WYSIWYG	Forgiveness
9	Perceived Stability	Forgiveness	Aesthetic Integrity
10	Aesthetic Integrity	Perceived Stability	
11	Modelessness	Aesthetic Integrity	
12	Knowledge Audience	Modelessness	
13	Accessibility	Managing Complexity	
14		Worldwide Compatibility	
15		Universal Accessibility	

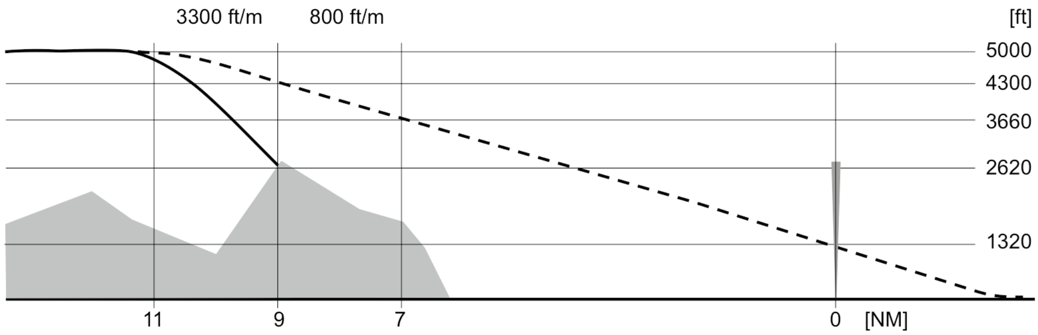
→ Apple Computer, Inc. (1995). Macintosh Human Interface Guidelines (385 pages). New York: Addison-Wesley
→ Apple Computer, Inc. (2005). Apple Human Interface Guidelines (344 pages). Cupertino: Apple, Inc.
→ https://developer.apple.com/ […] OSXHIGuidelines/DesignPrinciples.html.

Case studies

Airbus A320 FCU-Interface: Mode Awareness, CFIT, Air Inter 148DA, 20. January 1992

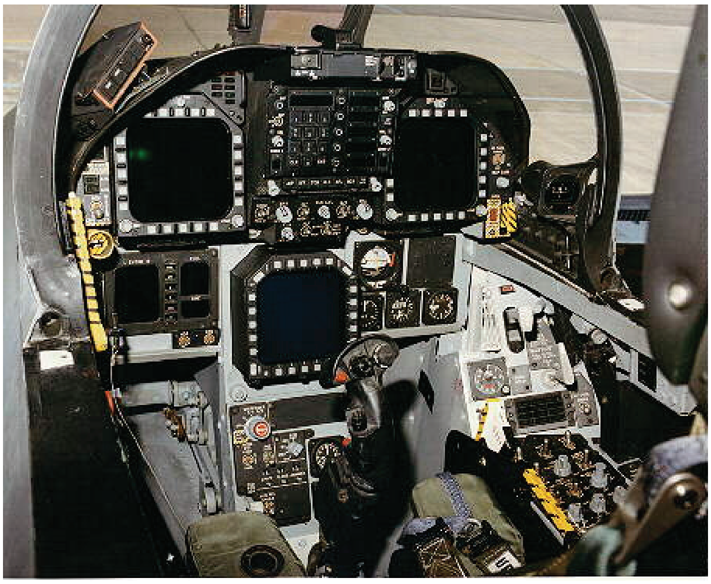
F/A-18 instrumentation: Spatial Disorientation - Recovery, LOC-I , 7. Avril 1998





→ Johnson, E.N. & Pritchett, A.R. (1995). Experimental Study of Vertical Flight Path Mode Awareness. 6th Symposium on Analysis, Design and Evaluation of Man-Machine Systems, Cambridge, MA.

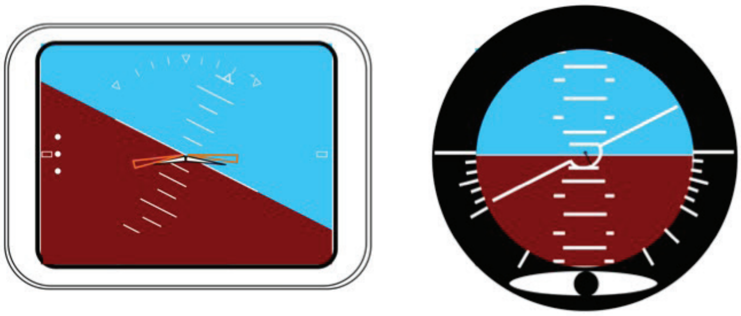
→ Pariés, J. (1994). Investigation probed root causes CFIT accident involving a new-generation transport. ICAO Journal July/August 1994, 37-41.



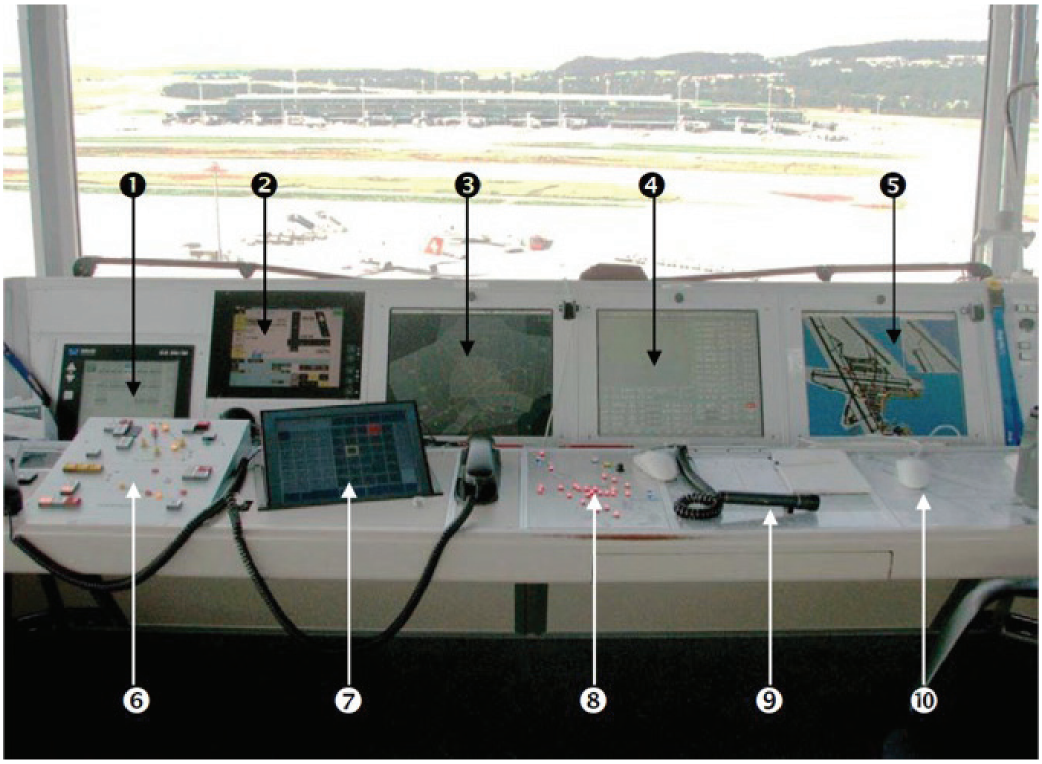
→ Huber, S. (2004). Interpretation von Fluglageanzeigen bei Darstellung mittels Head-up Display oder konventioneller Instrumente. Diplom ETH NDS.

→ Huber, S. (2006). Recovery from Unusual Attitudes: HUD vs. Back-up Display in a Static F/A-18 Simulator. Aviation, Space, and Environmental Medicine, 77, 4, 444-448.

Case studies
Saab 340B instrumentation, Inside-out vs. outside-in, LOC-I, 10. January 2000
Tower ATC Airport ZRH, Airprox SWR 202 / SWR 1326, 15. Mars 2011



→ BFU (2004). Schlussbericht Nr. 1781, Saab 340B, Unfall vom 10. Januar 2000.



→ SUST (2012). Schlussbericht Nr. 2136 über Airprox vom 15. März 2011.

5.3 Skills, Rules and Knowledge

Three levels of performance of skilled human operators (Rasmussen 1983):
(1) Knowledge-based behaviour
(2) Rule-based behaviour
(3) Skill-based behaviour (sensory-motor performance)

Three stages of skill acquisition (Anderson 2015):
1. Cognitive stage refers to the development of a declarative encoding of the skill. A set of facts relevant to the skill is committed to the memory for to use in general problem-solving methods, for example target mean analysis or analogies.

After the repeated use of the skill, a form of learning takes place, i.e. a compilation of the knowledge, which generates a procedural representation of the skill:
2. Associative stage. For certain areas of the skill, the declarative is replaced by a procedural representation, or both representations can coexist. „However, the procedural, not the declarative, knowledge governs the skilled performance.“ (Anderson 2015, p.212).

3. Autonomous stage. The resulting procedure is increasingly automated by practice. Thus the skill-based action can increasingly be executed more quickly, more precisely and more appropriately. The verbal declaration fades out and disappears completely.

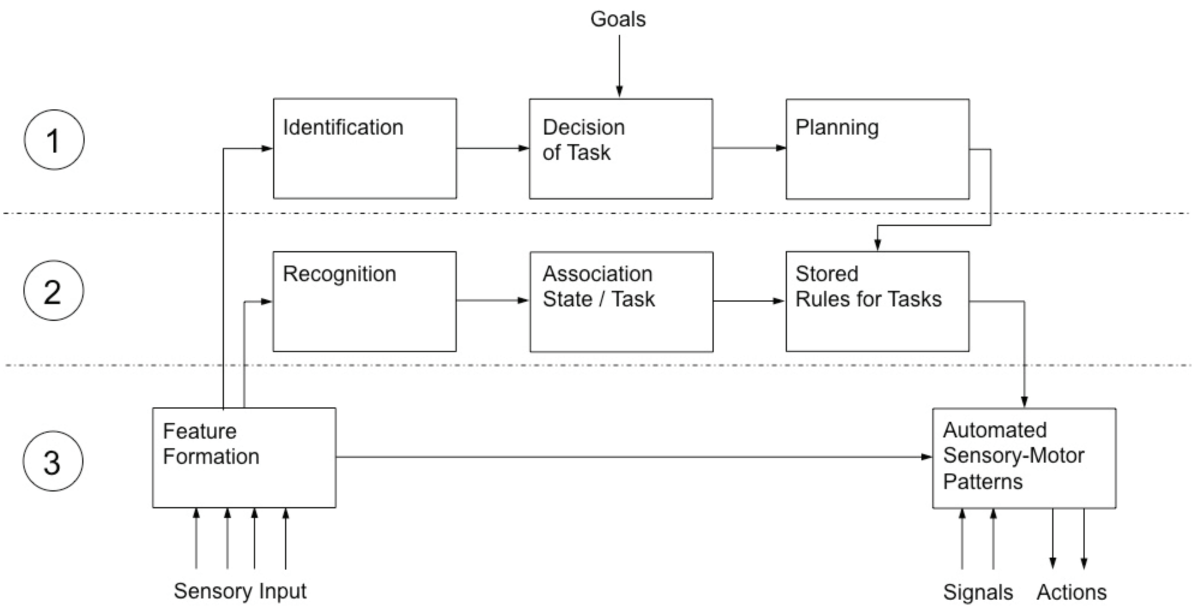


Fig. 13 Simplified illustration of the three levels of performance (Rasmussen 1983, p.258).

Anderson, J.R. (2015).
Cognitive Psychology and ist Implications.
New York: Worth Publishers.

Rasmussen, J. (1983).
Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models.
IEEE Trans. Systems, Man, Cybernetics, SMC-13, 257-266.

6. Environmental Conditions

Aspects / Factors
- Lighting / visual
- Noise / auditory
- Vibration / vibrational
- Indoor climate / thermal
- Radiation
- Hazardous Substances

Regulation
SECO (2016). Wegleitung zur Verordnung 3 und 4 des Schweizer Arbeitsgesetzes.
→ www.seco.admin.ch

6.1 Lighting
→ Boyce, P.R. (2003). Human Factors in Lighting. Taylor & Francis.

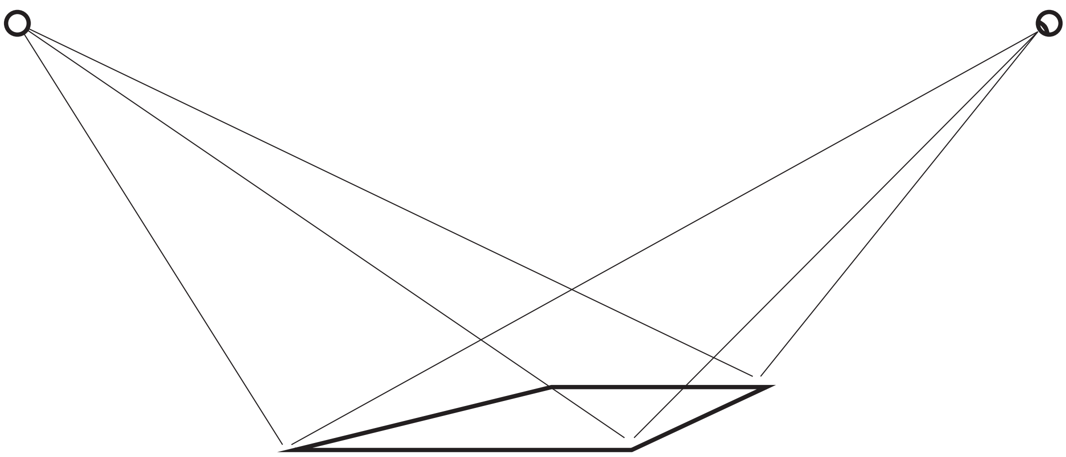


Fig. 14 Source of light, Luminous flux, Luminous intensity, Illuminance, Luminance.

Luminous flux, Lichtstrom Lumen [lm]
Quantity of radiant flux which expresses its capacity to produce visual sensation.

Luminous intensity, Lichtstärke Candela [cd = lm/Ω]
The luminous flux emitted in a cone containing the given direction divided by the solid angle Ω of the cone.

Illuminance, Beleuchtungsstärke Lux [$lx = lm/m^2$]
The luminous flux per surface area at a point on this surface.

Luminance, Leuchtdichte Candela/m^2 [cd/m^2]
The luminous flux emitted in direction divided by the product of the projected area of the source element perpendicular to the direction and the solid angle containing that direction.

Tab. 7 Typical illuminance and luminance values.

Situation	Illuminance [lx]	Typical surface	Luminance [cd/m^2]
Clear sky in summer	150´000	Grass	2´900
Overcast sky in summer	16´000	Grass	300
Textile inspection	1´500	Light gray cloth	140
Office work	500	White paper	120
Heavy engineering	300	Steel	20
Good road lighting	10	Concrete road surface	1,0
Moonlight	0,5	Asphalt road surface	0,01

Tab. 8 Recommendation of illuminance values.
→ Eastman Kodak (1983). Ergonomic Design for People at Work, Vol. 1, New York: VNR.
→ SECO (2016). Wegleitung zur Verordnung 3 und 4 des Schweizer Arbeitsgesetzes.

Type of work	Illumination [lx]
Simple orientation for short temporary visits.	50 - 100
Corridors, storerooms, working spaces where visual tasks are only occasionally performed.	100 - 200
Performance of visual tasks of high contrast or large size: reading printed material, rough bench and machine work, rough assembly.	200 - 500
Performance of visual tasks of medium contrast or small size: reading pencil handwriting, medium bench and machine work, difficult inspection, medium assembly	500 - 1´000
Writing, reading, computer work, CAD	> 500
Performance of visual tasks of low contrast or very small size, very difficulty inspection.	1´000 - 2´000
Performance of visual tasks of low contrast or very small size over a prolonged period: fine assembly, highly difficult inspection, fine bench and machine work.	2´000 - 5´000
Performance of very special visual tasks of extremely low contrast and small size: some surgical procedures.	10´000 - 20´000
Escape routes, emergency lighting.	> 1

Tab. 9 Recommendation of reflectance values.

Reflectance [%]	DIN 5035-7	Grandjean 1988
Desktop surfaces	20 - 50	
Monitor frame, Keyboard	20 - 50	
Ceiling	> 60	80 - 90
Walls	40 - 80	40 - 60
Flooring	15 - 40	20 - 40

DIN 5035-7:2006.
Beleuchtung mit künstlichem Licht - Teil 7: Beleuchtung von Räumen mit Bildschirmarbeitsplätzen (Artificial Lighting - Part 7: Lighting of interiors with visual displays work stations).
Grandjean, E. (1988). Fitting the task to the man. New York: Taylor & Francis.

6.2 Noise

Noise is any disturbing or harmful sound.

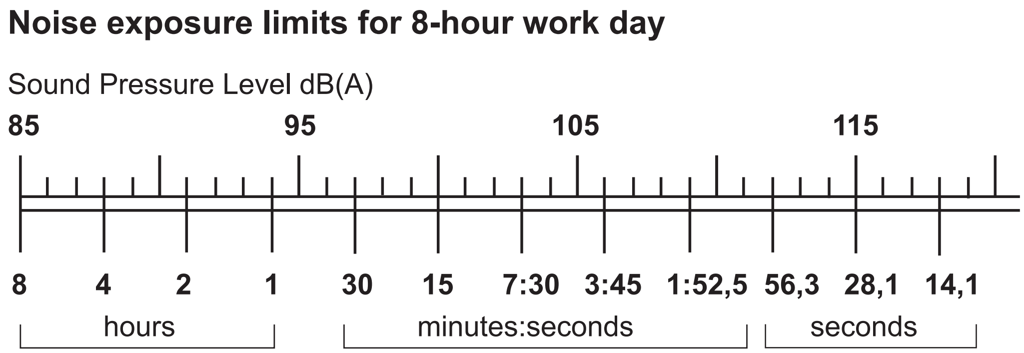


Fig. 15 Noise exposure limits for 8-hour work day.

Sound pressure level (SPL) and decibel (dB)

1. Reference of pressure variations or sound waves: barometric, ambient pressure [Pa].
2. Sound pressure value (effective, root mean square): $p_{eff} = \sqrt{\frac{1}{T}\int_0^T p^2\, dt}$
3. Relation of sound power (input, emitter) and sound pressure: $N \sim p^2$, $\frac{N_1}{N_2} = \frac{p_1^2}{p_2^2}$
4. Sound Intensity (Recipient): I [W/m²]
   Power transmission per unit area perpendicular to sound wave direction.
5. Human perception
   Sound intensity range: 10^{-12} W/m² - 1 W/m² (1:100´000´000´000)
   Frequency range: 16 Hz - 16 kHz (20 kHz).
6. Definition of bel (B) ≈ Logarithm of sound intensity quotient (bel ~ A.G. Bell).

   $\lg(\frac{1W/m^2}{10^{-12}W/m^2}) = \lg\frac{1}{10^{-12}} = \lg 10^{12} = 12$ → sound intensity range: values 0 - 12 B.
7. Practice: accuracy of 1/10 Bel is sufficient, thus Factor 10 (deci) simplifies the legibility.
   Definition of deci-bel = decibel (dB) is 1 B = 10 dB or:

   $\lg(\frac{I_1}{I_2})B = 10\lg(\frac{I_1}{I_2})dB$
8. Setting reference values of:
   Sound intensity $I_0 = 10^{-12}$ W/m²
   Sound pressure p_0 = 20 µPa

9 Sound intensity level → sound pressure level (SPL):

$$10\lg(\frac{I}{I_0})dB = 10\lg(\frac{p^2}{p_0^2})dB = 10\lg(\frac{p}{p_0})^2 \rightarrow SPL = 20\lg(\frac{p}{p_0})$$

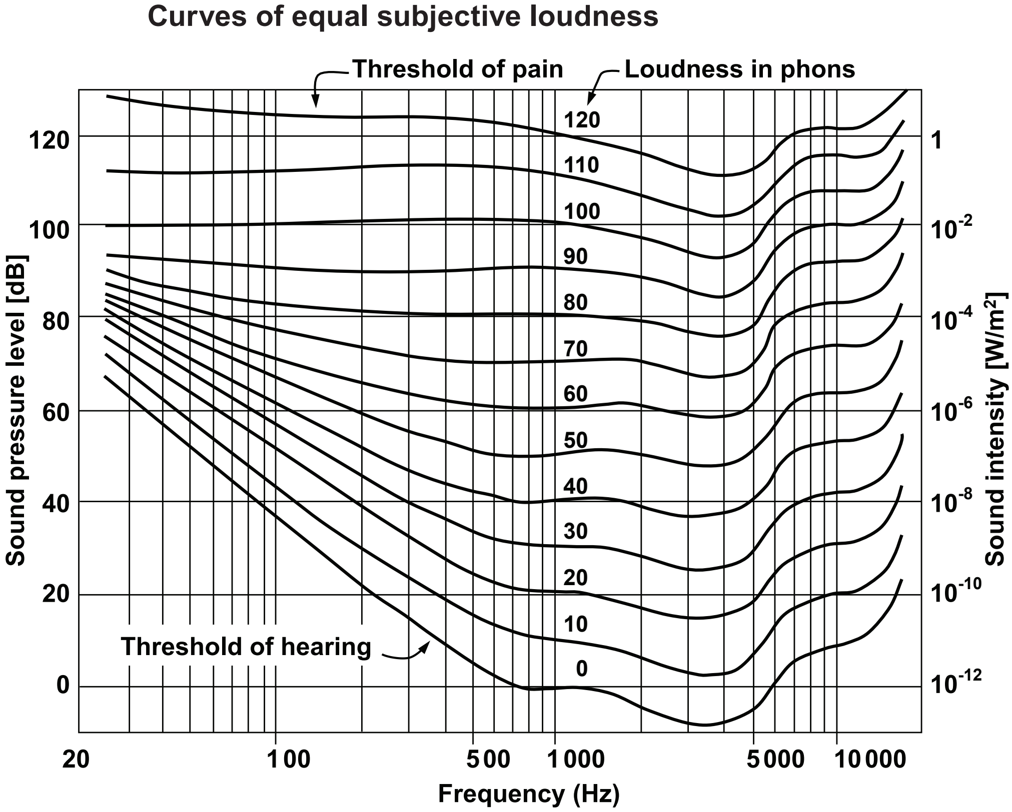


Fig. 16 Curves of equal subjective loudness in assessment with pure tones.

→ Goldstein, E.B. (2002). Wahrnehmungspsychologie. Heidelberg: Spektrum,
Fletscher, H. & Munson, W.A. (1933). Loudness: Its definition, measurement, and calculation. Journal of the Acoustical Society of America, 5, 82-108.

Human perception of noise: 1 dB is the smallest change to distinguish, a 10 dB increase is rated as twice as loud. Frequency dependence: A-, B-, C-filter for sound measurements.

Tab. 10 Orientation about sound pressure level (SPL), sound pressure and sound intensity.

Thresholds	SPL [dB]	sound pressure [Pa]	sound intensity [W/m²]
Hearing	0	$20 \cdot 10^{-3}$	10^{-12}
Pain	120 - 140	20	1

Multiple, incoherently (no interference) sources of sound:
Duplication of the sound intensity: lg(a/b), a=2b, lg(2)=0,301..., 10 dB → SPL + 3 dB
For example: 80 dB + 80 dB = 83 dB or 0 dB + 0 dB = 3 dB.
k times the same intensity → SPL + 10 lg(k) dB

Tab. 11 Typical A-weighted sound pressure levels.

Situation	dB(A)	Situation	dB(A)
Breathing (d=1m)	20	Manufacturing	80-90
Quite residence, north rim of grand canyon	30	Construction side	100
Conversation, class room chatter	60-70	Ship´s engine room, rock concert	120
Freight train (d=30m), busy highway	80-90	Jet taking off (d=60m)	130

Occupational noise exposure
Energy-equivalent and time-weighted average sound levels

Equivalent continous sound level L_{eq} and sound exposure level SEL or L_E

- L_{eq} is the steady sound pressure level which, over a given period of time, has the same total energy as the actual fluctuating noise.
- L_E is similar to L_{eq} in that the total sound energy is integrated over the measurement period, but instead of then averaging it over the entire measurement period, a reference duration of one second is used. → Bruel&Kjaer Application notes.

Index "A": A-weighted sound pressure levels (frequency dependence of loudness perception).
Index "C": C-weighted sound pressure levels (impact of peaks).

Lärmexpositionspegel (noise exposure level) $L_{EX,8h} = L_{eq,8h} = fn(L_{eq,Ti})$, i=1,...,N

Tab. 12 Noise exposure limits and measures (M_1,...) in Switzerland and Germany.
→ Suva (2015). Gehörgefährdender Lärm am Arbeitsplatz.
→ BRD (2007). Lärm- und Vibration-Arbeitsschutzverordnung.
→ CH (1996). Verordnung über den Schutz des Publikums von Veranstaltungen vor gesundheitsgefährdenden Schalleinwirkungen und Laserstrahlen.

	Switzerland			Germany	
	M_1	M_2	M_3	M_1	M_2
$L_{EX,8h}$	85 dB(A)	-	-	80 dB(A)	85 dB(A)
$L_{EX,2000h}$	-	85 dB(A)	88 dB(A)	-	-
$L_{pC,peak}$	135 dB(C)	135 dB(C)	135 dB(C)	135 dB(C)	137 dB(C)
L_E	< 120 dB(A)	120 dB(A)	125 dB(A)	-	-

L_{EX} event time	< 93 dB(A) -	< 96 dB(A) - < 100 dB(A) if < 3 h	< 100 dB(A) if > 3h

Tab. 13 Task-related noise exposure limits L_{EX} in Switzerland
→ Suva (2015). Gehörgefährdender Lärm am Arbeitsplatz.

Type of work, example of tasks	normal demands	enhanced demands
Mainly manual, hand-crafting routine tasks with short-term or low demand on concentration. Processing and manufacturing machinery work, workshop tasks, service and inspection.	< 85 dB(A)	≤ 75 dB(A)
Repetition of mental tasks with continuously or temporarily high demand on concentration. Office work and comparable tasks, administrative tasks, selling.	≤ 65 dB(A)	≤ 55 dB(A)
Mental tasks with continuously high demand on concentration and creativity. Scientific work, engineering, software development, translating.	≤ 50 dB(A)	≤ 40 dB(A)
Background noise: office, OR, class room	40 dB(A)	-
Background noise: control room	60 dB(A)	-

7. System Analysis and Usability Testing

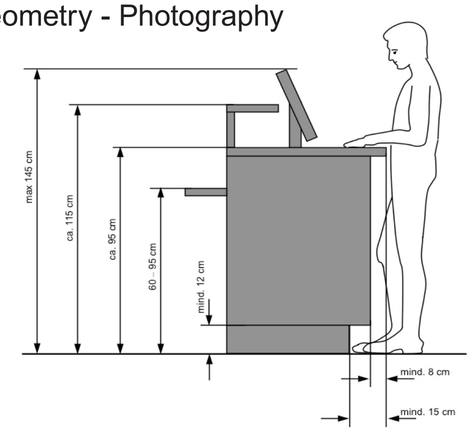
7.1 Feldstudie - Struktur, Inhalte, Leitfragen

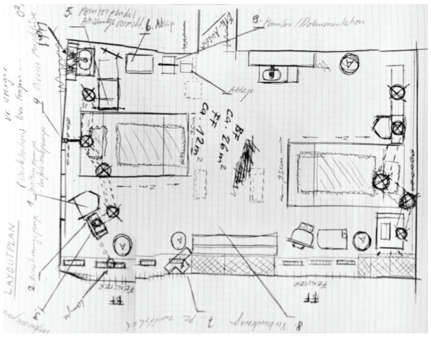
Auftrag und Zielsetzung	Auftrag ist eine Analyse eines bestimmten Arbeitssystems und der Arbeitsplätze hinsichtlich ergonomischer Gestaltung. Ziel ist es, das System, seine Elemente und Prozesse zu beschreiben, positive Aspekte und Schwachstellen zu ermitteln und Verbesserungen aus Sicht der Ergonomie vorzuschlagen.
Methode/Vorgehensweise	Wann und wie wurden die erforderlichen Daten erhoben? Nach welchen Kriterien wurden die Bewertung und die Vorschläge zur Verbesserung durchgeführt?
Systembeschreibung	
- Räumliche Situation/Raumlayout	Welches System wird betrachtet und untersucht, welche Systemgrenzen gewählt? Wie ist der Grundriss, die Anordnung von Arbeitsplätzen, Zugängen, Wege innerhalb des Systems?
- Arbeitsaufgaben	Wer, welche Berufsgruppe wird betrachtet und was müssen sie im betrachteten System leisten/erreichen? Für welche Aufgaben sind sie verantwortlich?
- Arbeitsorganisation	Wie werden die Aufgaben hinsichtlich Personaleinsatz und Zeitstruktur ausgeführt? Wie sind die Arbeitszeiten, Schichten, Pausen und Formen der Zusammenarbeit?
- Arbeitsplatz/-plätze	Wie ist der Arbeitsplatz oder sind die Arbeitsplätze aufgebaut, welche geometrischen Abmessungen (Arbeitshöhen, Freiräume, Greif-/Blickräume)? Aus welchen Arbeitsmitteln besteht der Arbeitsplatz, welche Funktionen haben diese?
- Arbeitsprozesse/Arbeitsabläufe	Was wird der Reihe oder zeitlichen Abfolge nach am Arbeitsplatz oder den Arbeitsplätzen ausgeführt? In welchen Teilschritten oder Teilprozessen wird die Arbeitsaufgabe ausgeführt? Kann ein Ablaufplan dargestellt werden?
- Arbeitsumgebung	Welche Verhältnisse liegen bezüglich Licht/Beleuchtung, störender/schädigender Schall, Raumklima, Strahlungen, Schadstoffe vor?
Tätigkeitsanalyse	
- Untersuchte Tätigkeiten	Welche Tätigkeiten wurden zur eigenen Untersuchung definiert, was wurde gezielt beobachtet, wie wurde registriert?
- Abfolge/Dauer/Häufigkeiten	Was wurde ermittelt, welches Auftreten in der Zeitstruktur hatten die ausgewählten Tätigkeiten?
Beurteilung und Verbesserungen	
- Positive Aspekte	Welche Aspekte, Begebenheiten, Bedingungen fallen einem Beobachter positiv hinsichtlich human well-being und overall system performance auf?
- Schwachstellen/Mängel	Schwachstellen können auch jeweils direkt mit den jeweiligen Verbessrungsvorschlägen aufgeführt sein.
- Verbesserungsvorschläge	Sowohl Schwachstellen wie Verbesserungsvorschläge können zwecks besserer Kommunikation nummeriert werden.
Diskussion	Welche Bedeutung oder Gewichtung haben die erkannten Schwachstellen für die Arbeitsqualität? Welche Einschränkungen - z.B. aufgrund des Vorgehens - bestehen?
Literatur	Welche Publikationen wurden im Bericht zitiert, welche können dem Leser als Grundlage/Vertiefung der im Bericht aufgeführten Zusammenhänge dienen?

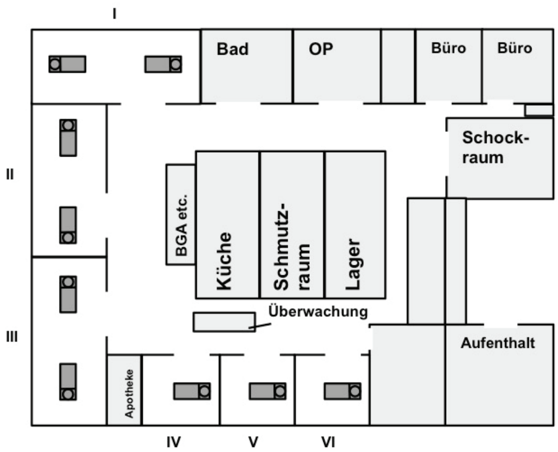
Case studies of systems analysis

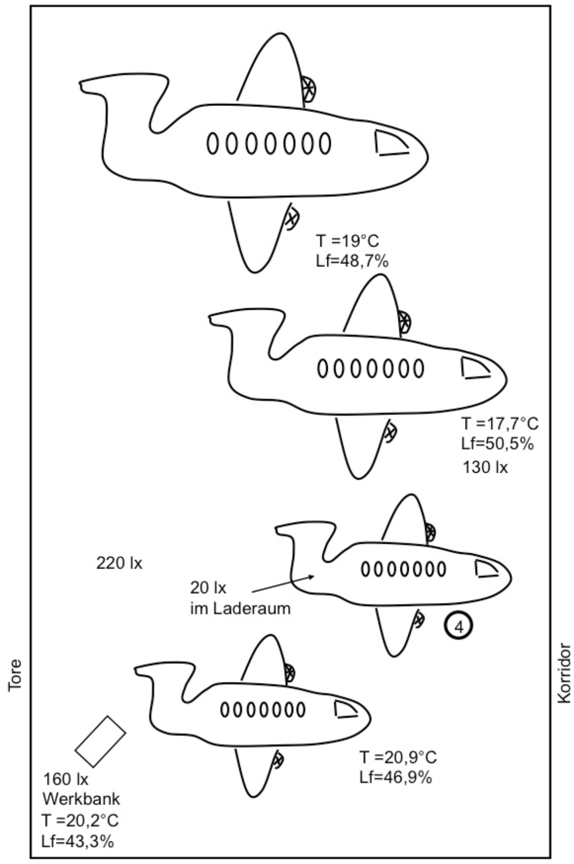
→ Held, J. (2007). Prospektive Ergonomie in der Neugestaltung komplexer Arbeitssysteme und Produkte. Habilitation ETH Zürich.

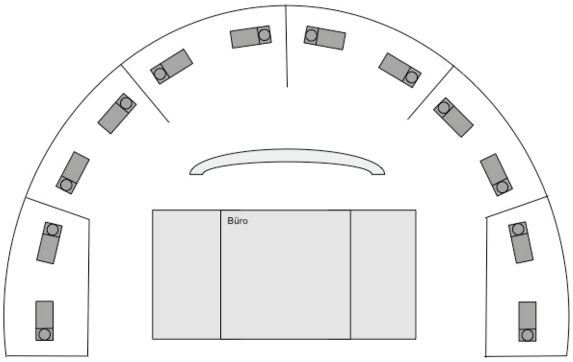
Description of room and work place layout.
- Grain of analysis, documents, plans
- Principle of divergence - convergence
- Geometry - Photography

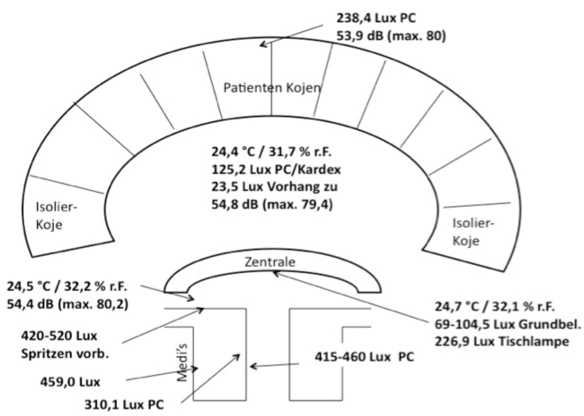












User-expert interaction and implicit knowledge
- Routine, procedural knowledge, expert´s paradox
- “Vehicles” for explanation, to show, demonstrate
- Problems of verbalisation, elicitation
- Robust, simple, graspable objects

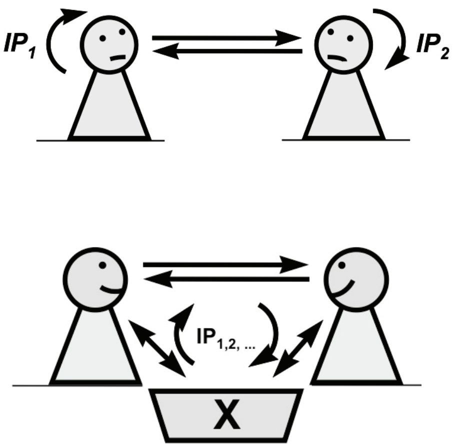


Fig. 17 User-Expert interaction without and with explanation support.

Communication in analysis vs. prototyping
- Consideration of visualisation, confrontation, reflection
- Mutual, reciprocal learning

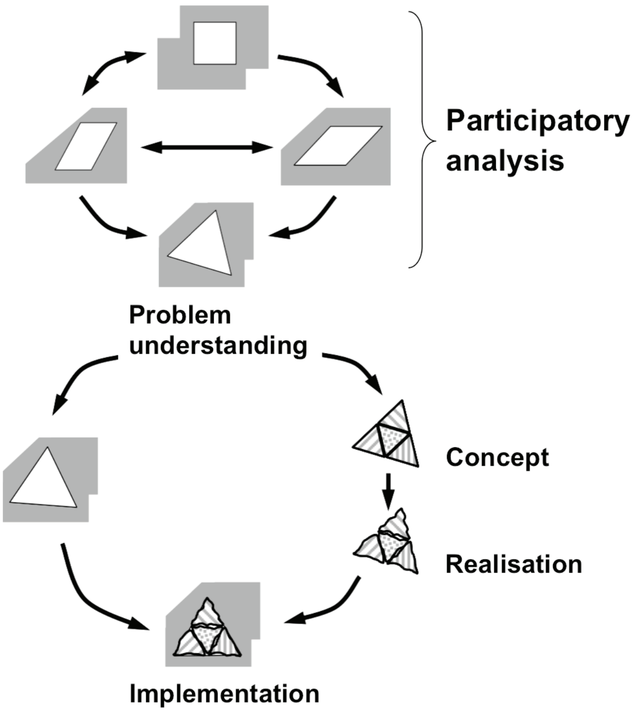
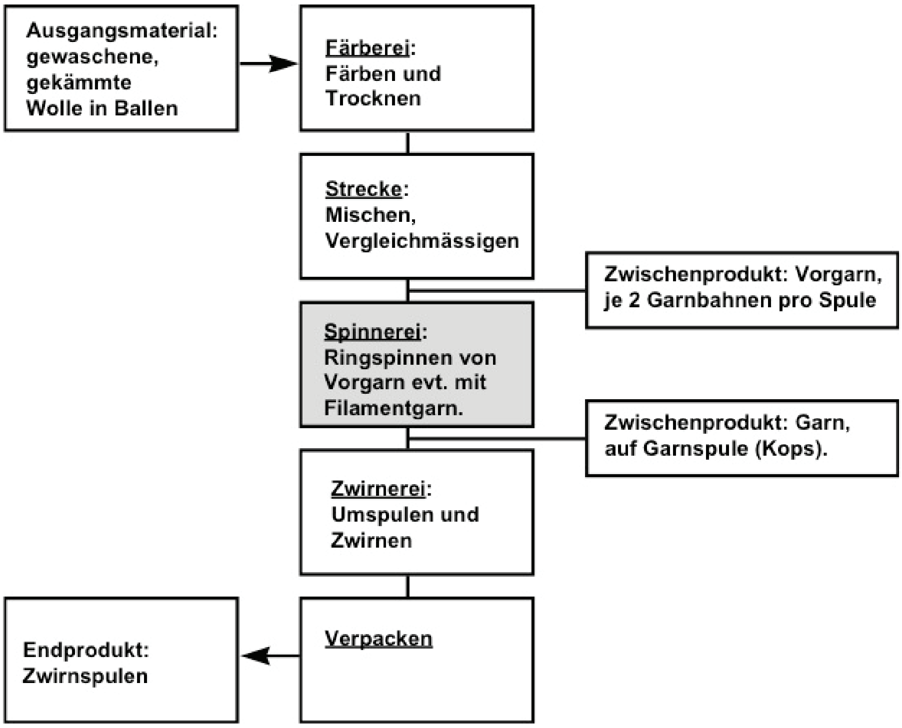
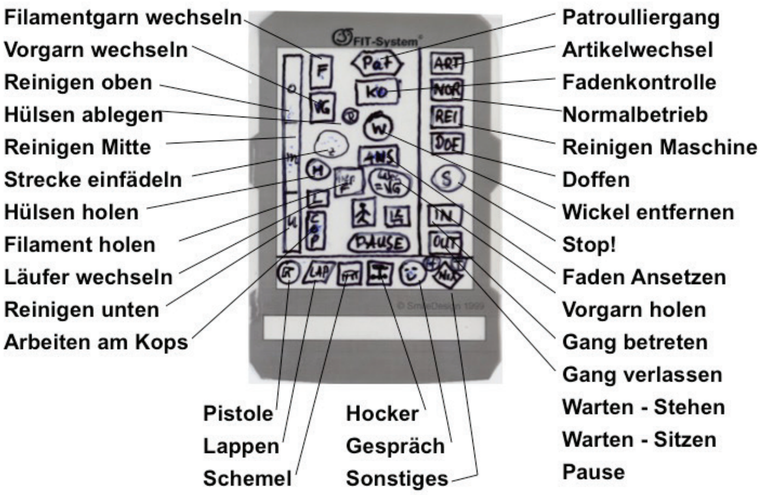


Fig. 18 Problem solving participatory design process.
→ Held, J. (2005). Partizipative Ergonomie. Aachen: Shaker.

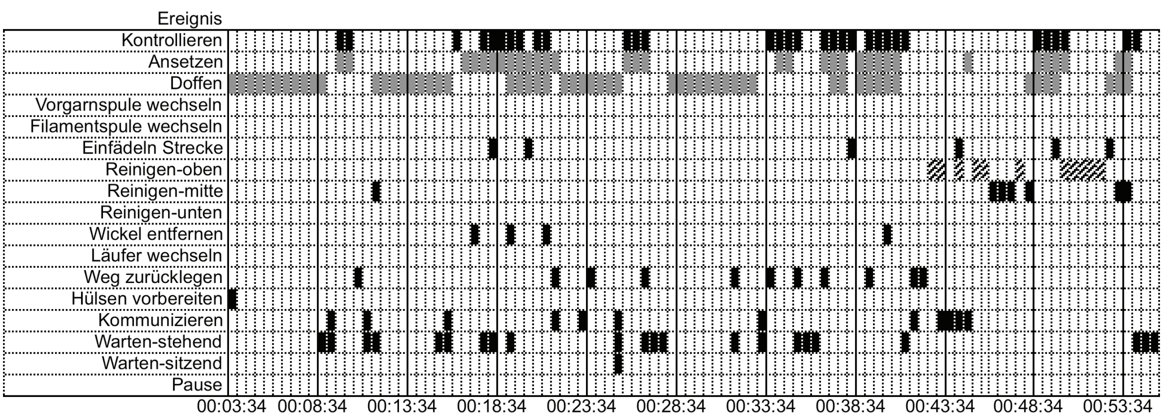
Work process and task analysis
- Black box, grey box charts
- Categories, taxonomy of tasks, subtasks, events
- Task / event recording, intensity, extensiveness, time-line charts

→ Held, J. (1999). Fitting the mental model - A new technique for computerised event recording In: D. Harris (Ed.): Engineering Psychology and Cognitive Ergonomics, Ashgate, p.293-300.





→ touch screen application for event recording:
FIT-System
iPad App & iBook



7.2 Usability Test - Struktur, Inhalte, Leitfragen

→ Rubin, J. & Chisnell, D. (2008). Handbook of Usability Testing -How to Plan, Design, and Conduct Effective Tests. Indianapolis: Wiley.

Ziel der Untersuchung	Überprüfung der Gebrauchstauglichkeit eines Produktes, um Aussagen in Bezug zur Effektivität, Effizienz der Mensch-Produkt Interaktion und zur Zufriedenheit des Benutzers über diese Interaktion treffen zu können
Produkt und Zielgruppe	Mit welchem Objekt/Produkt wird die Interaktion getestet? Welche problematischen Aspekte sind schon vor dem Test bekannt? Wer ist die Zielgruppe, durch welche Merkmale wird sie beschrieben?
Methode	
- Testaufbau	Welches Testszenario wurde gewählt und wie wurde es für den Test umgesetzt (z.B. nachgestellte Arbeitsumgebung)?
- Probanden	Anzahl und Merkmale, z.B. Alter, Geschlecht, Berufserfahrung, der Probanden.
- Testaufgaben und -durchführung	Welche Aufgaben müssen die Probanden mit dem Produkt ausführen, welche weiteren Aufgaben für den Test bewältigen, z.B. Fragen oder Fragebögen beantworten? Wie läuft der Test ab, in welcher Zeitstruktur, wann erfolgen welche Aufgaben, wie agiert die Testleitung?
Resultate	
- Probanden	Ggf. im Test ermittelte Angaben zu den Probanden, sofern nicht schon in Methode enthalten.
- Test	Welche quantitativen und qualitativen Inhalte konnten aus den Aufgaben, Befragungen, Beobachtungen ermittelt werden? Welche Probleme bezüglich der Gebrauchstauglichkeit wurden entdeckt?
Diskussion	Wie sind die Resultate einzuordnen, zu gewichten? Welche Relevanz haben sie für den Produkthersteller? Wie ist die Ergiebigkeit des Tests zu bewerten, welche neuen Erkenntnisse konnten gefunden werden? Welche Einschränkungen, Schwierigkeiten traten auf, mit welcher Relevanz für die Ergebnisse?
Literatur	Welche Publikationen wurden im Bericht zitiert, welche können dem Leser als Grundlage/Vertiefung der im Bericht aufgeführten Zusammenhänge dienen?
Anhang	ggf. z.B. Fragebögen, Protokolle.

Discussion of “five user assumption”:

Nielsen,J. & Landauer, T.K. (1993). A mathematical model of the finding of usability problems. Interchi ’93, ACM Computer-Human Interface Special Interest Group.

Faulkner, L. (2003). Beyond the five-user assumption: Benefits of increased sample sizes in usability testing. Behavior Research Methods, Instruments, & Computers, 35 (3), 379-383.

Literature

* online access

Standards

ISO 9241-11:2016	Ergonomie der Mensch-System-Interaktion – Teil 11: Gebrauchstauglichkeit: Begriffe und Konzepte (Ergonomics of human-system interaction - Part 11: Usability: Definitions and concepts).*
CEN-CENELEC (2014).	Guide 6, Guide for addressing accessibility in standards.*
ISO 6385:2014	Grundsätze der Ergonomie für die Gestaltung von Arbeitssystemen (Ergonomic principles in the design of work systems).*
ANSI/AAMI HE75:(R)2013	American National Standard, Association for the Advancement of Medical Instrumentation. Human Factors Engineering - Design of medical devices.
ISO 7250-2:2013	Summaries of body measurements from national populations.*
ISO 11064-4:2013	Ergonomische Gestaltung von Leitzentralen - Teil 4: Auslegung und Maße von Arbeitsplätzen (Ergonomic design of control centres - Part 4: Layout and dimensions of workstations).*
ISO 9241-303:2012	Ergonomie der Mensch-System-Interaktion - Teil 303: Anforderungen an elektronische optische Anzeigen (Part 303: Requirements for electronic visual displays).*
DIN 33408-1:2008	Körperumriss-Schablone - Teil 1: Für Sitzplätze (Body templates - Part 1: For seats of all kinds).*
ISO 9241-110:2006	Ergonomie der Mensch-System-Interaktion - Teil 110: Grundsätze der Dialoggestaltung (Ergonomics of human-system interaction - part 110: Dialogue principles).*
DIN 33402-2:2005	Ergonomie. Körpermaße des Menschen. Teil 2: Werte. (Ergonomics. Human body dimensions. Part 2: Values).*
DIN 5035-7:2004	Beleuchtung mit künstlichem Licht - Teil 7: Beleuchtung von Räumen mit Bildschirmarbeitsplätzen (Artificial Lighting - Part 7: Lighting of interiors with visual displays work stations).*
ISO 10075-2:2000	Ergonomische Grundlagen bezüglich psychischer Arbeitsbelastung - Teil 2: Gestaltungsgrundsätze. (Ergonomic principles related to mental workload - Part 2: Design principles).*

Books

Anderson, J.R. (2015).	Cognitive Psychology and ist Implications. New York: Worth Publishers.
Rubin, J. & Chisnell, D. (2008).	Handbook of Usability Testing - How to Plan, Design, and Conduct Effective Tests. Indianapolis: Wiley.*
Lueder, R. and Berg Rice, V.J. (2008).	Ergonomics for Children. Boca Raton: CRC.*
Held, J. (2005).	Partizipative Ergonomie. Aachen: Shaker.
Apple Computer, Inc. (2005).	Human Interface Guidelines (344 pages). Cupertino: Apple, Inc.*
Boyce, P.R. (2003).	Human Factors in Lighting. Tayor & Francis.*
Goldstein, E.B. (2002).	Wahrnehmungspsychologie. Heidelberg: Spektrum.
Tilley, A.R. (2002).	The Measure of Man and Woman. New Jersey: Wiley.
Galitz, W.O. (2002).	The Essential Guide to User Interface Design. New York: Wiley.
Pheasant, S. (2002).	Bodyspace. London: Taylor & Francis.
Apple Computer, Inc. (1995).	Macintosh Human Interface Guidelines (385 pages). New York: Addison-Wesley.*
Sanders, M.S. & McCormick, E.J. (1993).	Human Factors in Engineering and Design. London: McGraw-Hill.
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WHO Growth Charts	www.who.int/childgrowth/standards/en/
Human Interface Guidelines Apple OSX	https://developer.apple.com/ […] OSXHIGuidelines/DesignPrinciples.html
ILO/WHO Committee Occupational Health	http://www.ilo.org/safework