

Contents

1	Introduction	1
1.1	What is Human Factors Engineering?	2
1.2	Goals and Process of Human Factors Engineering	4
1.3	Scope of Human Factors Engineering	8
1.4	Systems Thinking	11
1.5	Scientific Base of Human Factors Engineering . .	12
1.6	Overview of the Book	13
	Questions	15
2	Design Methods	17
2.1	Human Factors in Design and Evaluation	19
2.1.1	System Design Processes	20
2.1.2	Human-Centered Design	22
2.2	Understanding Users, Context, and Tasks	25
2.3	How to Perform a Task Analysis	27
2.3.1	Step 1: Define Purpose and Required Data	27
2.3.2	Step 2: Collect Task Data	30
2.3.3	Step 3: Interpret Task Data	33
2.3.4	Step 4: Innovate from Task Data	37
2.4	Iterative Design and Refinement	40
2.4.1	Providing Input for System Specifications	40
2.4.2	Prototypes, Wireframes, and Mockups . .	44
2.4.3	Supporting Materials and Organizational Design	45
2.5	Evaluation	46
2.6	Summary	46
	Questions	48
3	Evaluation Methods	51
3.1	Purpose of Evaluation	53
3.2	Timing and Types of Evaluation	55
3.2.1	Literature Review, Heuristic Evaluation, and Cognitive Walkthrough	56
3.2.2	Usability Testing	58
3.2.3	Comprehensive Evaluations and Controlled Experiments	59
3.2.4	In-service Evaluation	60
3.3	Study Design	61
3.3.1	One-factor Designs	62
3.3.2	Multiple-factor Designs	63
3.3.3	Between-subjects Designs	64

3.3.4	Within-subjects Designs	64
3.3.5	Mixed Designs	64
3.3.6	Sampling People, Tasks, and Situations	65
3.4	Measurement	65
3.5	Data Analysis	67
3.5.1	Analysis of Controlled Experiments	67
3.5.2	Analysis of Continuous Variables in Descriptive Studies	69
3.6	Drawing Conclusions and Communicating Results	70
3.6.1	Statistical Significance and Type I and Type II Errors	71
3.6.2	Statistical and Practical Significance	72
3.6.3	Generalizing and Predicting	73
3.7	Driver Distraction: Example of a Factorial Design	73
3.8	Ethical Issues	74
3.9	Summary	75
	Questions	77

I Cognitive Considerations 79

4	Visual Sensory System	85
4.1	Visual Environment	86
4.1.1	Wavelength and Color	87
4.1.2	Light Intensity	88
4.1.3	Light Sources	91
4.1.4	Optic Flow and Ecological Optics	92
4.2	The Receptor System: The Eye	93
4.2.1	The Lens and Accommodation	93
4.2.2	The Receptors: Rods and Cones	95
4.3	Sensory Processing Characteristics	98
4.3.1	Visual Acuity	98
4.3.2	Contrast Sensitivity	100
4.3.3	Color Vision	102
4.3.4	Night Vision	103
4.4	Cognitive Influence on Visual Perception	103
4.4.1	Depth Perception	104
4.4.2	Visual Search and Detection	107
4.4.3	Detection	111
4.4.4	Discrimination	115
4.4.5	Absolute Judgment	116
4.5	Visual Influence on Cognition	117
4.5.1	Light and Circadian Desynchronization	117
4.5.2	Meaning and Emotional Influence of Color	118
4.6	Summary	118
	Questions	120

5 Auditory, Tactile, and Vestibular Systems 123

5.1	Auditory Environment	124
5.1.1	Amplitude, Frequency, Envelope, and Location	124
5.1.2	Sound Intensity	127

5.1.3 Sound Field	129
5.1.4 Sound Sources and Noise Mitigation	131
5.2 The Receptor System: The Ear	135
5.2.1 Anatomy of the Ear	135
5.2.2 Masking, Temporary Threshold Shift, and Permanent Threshold Shift	136
5.3 Auditory Sensory Processing Characteristics	138
5.3.1 Loudness and Pitch	139
5.4 Cognitive Influence on Auditory Perception	140
5.4.1 Detection and Localization	140
5.4.2 Alarms	142
5.4.3 Speech Communication	147
5.5 Auditory Influence on Cognition: Noise and Annoyance	152
5.6 Other Senses	154
5.6.1 Touch: Tactile and Haptic Senses	154
5.6.2 Proprioception and Kinesthesia	155
5.6.3 The Vestibular Senses	155
5.7 Summary	157
Questions	159
6 Cognition	161
6.1 Cognitive Environment	163
6.2 Information Processing Model of Cognition	164
6.3 Selective Attention and Perception	165
6.3.1 Mechanisms of Selective Attention	166
6.3.2 Mechanisms of the Perceptual Processes .	168
6.3.3 Implications of Selective Attention and Perception for Design	170
6.4 Working Memory	172
6.4.1 Mechanisms of Working Memory	172
6.4.2 Limits of Working Memory	174
6.4.3 Implications of Working Memory for Design	176
6.5 Long-Term Memory	179
6.5.1 Mechanisms of Long-Term Memory	181
6.5.2 Effect of Repetition: Habits	183
6.5.3 Organization of Information in Long-Term Memory	185
6.5.4 Prospective Memory for Future Actions .	186
6.5.5 Implications of Long-Term Memory for Design	187
6.6 Divided Attention and Time-Sharing	189
6.6.1 Task Difficulty and Mental Workload	189
6.6.2 Task Resource Structure	190
6.6.3 Confusion	193
6.6.4 Task Switching	193
6.6.5 Training and Individual Differences	197
6.7 Summary	197
Questions	199
7 Decision Making and Macrocognition	201
7.1 Macrocognitive Environment	203

7.2	Levels of Behavior: Skill and Expertise	205
7.3	Decision Making	209
7.3.1	Normative and Descriptive Decision Making	211
7.4	Balancing Intuitive, Heuristic, and Analytic Decision Making	215
7.4.1	Vulnerabilities of Heuristics: Biases	216
7.4.2	Benefits of Heuristics and the Cost of Biases	223
7.4.3	Principles for Improving Decision Making	223
7.5	Situation Awareness	228
7.5.1	Measuring Situation Awareness	229
7.5.2	Principles for Improving Situation Awareness	230
7.6	Problem Solving and Troubleshooting	232
7.6.1	Principles for Improving Problem Solving and Troubleshooting	233
7.7	Planning and Scheduling	234
7.7.1	Principles for Improving Planning and Scheduling	235
7.8	Metacognition	235
7.8.1	Principles for Improving Metacognition	237
7.9	Summary	238
	Questions	240
8	Displays	243
8.1	Types of Displays and Tasks	245
8.2	Fifteen Principles of Display Design	246
8.2.1	Principles Based on Attention	247
8.2.2	Perceptual Principles	249
8.2.3	Memory Principles	250
8.2.4	Mental Model Principles	251
8.2.5	Summary of Principles	252
8.3	Alerts	253
8.4	Labels and Icons	253
8.5	Monitoring Displays	255
8.6	Integrative Displays	258
8.6.1	Display Layout	259
8.6.2	Head-Up Displays and Display Overlays	262
8.6.3	Head-Mounted Displays	263
8.6.4	Configural Displays	265
8.6.5	Putting It All Together: Supervisory Displays	266
8.7	Navigation Displays and Maps	268
8.7.1	Route Lists and Command Displays	269
8.7.2	Maps	269
8.8	Data Visualization and Graph Design	273
8.8.1	Matching Types of Graphs to Questions	273
8.8.2	Mapping Data to Display Dimensions	274
8.8.3	Proximity	275
8.8.4	Legibility	276
8.8.5	Clutter	276
8.8.6	Interactive Data Visualization	278
8.9	Summary	278
	Questions	280

9 Controls	283
9.1 Types of Controls and Tasks	284
9.2 Information Theory: Response Selection and Execution	286
9.3 Fifteen Principles for Discrete Controls	286
9.3.1 Attention Principles	287
9.3.2 Perceptual Principles	288
9.3.3 Memory Principles	290
9.3.4 Mental Model Principles	291
9.3.5 Response Selection Principles	292
9.3.6 Summary of Principles	296
9.4 Discrete Controls: Buttons and Switches	296
9.5 Discrete Controls: Keyboards	298
9.5.1 Numerical Data Entry	298
9.5.2 Text Data Entry	299
9.6 Discrete Controls: Voice Input	300
9.6.1 Benefits of Voice Control	300
9.6.2 Costs of Voice Control	301
9.7 Continuous Control: Position and Track	302
9.7.1 The Tracking Loop: Basic Elements	303
9.7.2 Input and Bandwidth	305
9.7.3 Control Order	306
9.7.4 Stability	310
9.7.5 Open-loop Versus Closed-loop Systems	311
9.8 Pointing Devices	311
9.8.1 Task Performance Dependence	313
9.8.2 The Work Space Environment	313
9.9 Displays for Tracking	315
9.10 Remote Manipulation, Teleoperation, and Telerobotics	316
9.10.1 Time Delay	316
9.10.2 Depth Perception and Image Quality	317
9.10.3 Proprioceptive Feedback	317
9.10.4 Design Solutions for Teleoperation	317
9.11 Summary	318
Questions	320
10 Human-Computer Interaction	323
10.1 Matching Interaction Style to Tasks and Users	326
10.1.1 Understanding Users and Their Tasks	326
10.2 Interaction Styles	328
10.3 Theories for Interface and Interaction Design	335
10.3.1 Goal-directed Behavior	336
10.3.2 Affect, Emotion, and Aesthetics	340
10.4 Fifteen Principles for HCI Design	341
10.4.1 Attention Principles	341
10.4.2 Perception Principles	342
10.4.3 Memory Principles	342
10.4.4 Mental Model Principles	343
10.4.5 Response Selection Principles	344
10.4.6 Interaction Principles	344
10.4.7 Summary of Principles	345

10.5	Interactive Visualization	346
10.6	Website and Application Design	348
10.7	Tangible and Wearable Technology	349
10.8	Computers in Cars	351
10.9	Evaluation Criteria for HCI	352
10.10	Summary	353
	Questions	355
11	Human-Automation Interaction	357
11.1	Why Automate?	359
11.2	Types of Automation and Types of Tasks	361
11.2.1	Types of Automation	361
11.2.2	Types of Tasks	364
11.3	Problems with Automation	364
11.3.1	Automation Reliability	365
11.3.2	Trust: Calibration and Mistrust	366
11.3.3	Overtrust, Complacency, and Out-of-the-loop Behavior	367
11.3.4	Workload and Situation Awareness	370
11.3.5	Mode Confusion and Managing Multiple Elements of Automation	371
11.3.6	Loss of Human Cooperation	371
11.3.7	Job Satisfaction	371
11.3.8	Training and Certification	372
11.4	Allocating Functions between People and Automation	372
11.5	Fifteen Principles of Human-Centered Automation	375
11.5.1	Mental Model Principles	375
11.5.2	Attention Principles	377
11.5.3	Perception Principles	378
11.5.4	Response Selection Principles	378
11.5.5	Interaction Principles	379
11.5.6	Organizational Principles	381
11.5.7	Summary of Principles	383
11.6	Increasingly Autonomous Technology	383
11.7	Summary	385
	Questions	387
12	Engineering Anthropometry and Workspace Design	389
12.1	Human Variability and Statistics	392
12.1.1	Human Variability	392
12.1.2	Statistical Analysis	394
12.2	Anthropometric Data	395
12.2.1	Measurement Devices and Methods	395
12.2.2	Civilian and Military Data	397
12.2.3	Structural and Functional Data	401
12.2.4	Use of Anthropometric Data in Design	402
12.3	Principles for Workspace Design	405
12.3.1	Clearance Requirement of the Largest Users	406
12.3.2	Reach Requirements of the Smallest Users	406
12.3.3	Special Requirements of Maintenance	408
12.3.4	Adjustability Requirements	408

12.3.5 Visibility and Normal Line of Sight	409
12.3.6 Component Arrangement	410
12.4 Design for Standing and Seated Work	414
12.4.1 Choosing between Standing and Seated Work	414
12.4.2 Work Surface Height	415
12.4.3 Work Surface Depth	415
12.4.4 Work Surface Inclination	416
12.5 Summary	417
Questions	418
13 Biomechanics of Work	419
13.1 The Musculoskeletal System	421
13.1.1 Bones and Connective Tissues	421
13.1.2 Muscles	422
13.2 Biomechanical Models	424
13.2.1 Single-segment Planar Static Model	425
13.3 Low-back Problems	427
13.3.1 Low-back Biomechanics of Lifting	427
13.4 NIOSH Lifting Guide	430
13.4.1 Manual Materials Handling	435
13.4.2 Seated Work and Chair Design	437
13.5 Cumulative Trauma Disorders	439
13.5.1 Common Forms of CTD	439
13.5.2 Causes and Prevention of CTDs	441
13.5.3 Hand-Tool Design	442
13.6 Summary	445
Questions	446
14 Work Physiology	449
14.1 Muscle Structure and Metabolism	451
14.1.1 Muscle Structure	451
14.1.2 Aerobic and Anaerobic Metabolism	452
14.2 Circulatory and Respiratory Systems	454
14.2.1 The Circulatory System	455
14.2.2 The Respiratory System	459
14.3 Energy Cost of Work and Workload Assessment	461
14.3.1 Energy Cost of Work	461
14.3.2 Measurement of Workload	463
14.4 Work Capacity and Whole-body Fatigue	468
14.4.1 Short-term and Long-term Work Capacity	468
14.4.2 Causes and Control of Whole-body Fatigue	470
14.4.3 Static Work and Local Muscle Fatigue	473
14.5 Summary	475
Questions	477
15 Stress and Workload	479
15.1 Environmental Stressors	481
15.1.1 Motion	482
15.1.2 Thermal Stress	483
15.1.3 Air Quality	484
15.2 Psychological Stressors	485
15.2.1 Cognitive Appraisal	485

15.2.2	Ethical Issues	486
15.2.3	Level of Arousal	486
15.2.4	Performance Changes with Overarousal	487
15.2.5	Measuring Stress	488
15.2.6	Remediation of Psychological Stress	488
15.3	Life Stress	489
15.4	Workload and Overload	490
15.4.1	The Timeline Model	491
15.4.2	Mental Workload Measurement	493
15.4.3	Overload Remediations	496
15.5	Vigilance, Fatigue, and Sleep Disruption	497
15.5.1	Vigilance and Underarousal	498
15.5.2	Vigilance Remediations	499
15.5.3	Sleep Disruption	500
15.5.4	Sleep Deprivation and Performance Effects	500
15.5.5	Circadian Rhythms	501
15.5.6	Circadian Disruption	503
15.5.7	Sleep Disruption Remediation	504
15.6	Summary	506
	Questions	508
16	Safety and Accident Prevention	511
16.1	Costs and Causes of Accidents	513
16.2	Safety Legislation	513
16.2.1	Workers' Compensation and Liability	514
16.2.2	Establishment of OSHA and NIOSH	515
16.2.3	Product Liability	516
16.3	Causes and Contributers to Accidents	517
16.3.1	Worker Characteristics	518
16.3.2	Job Characteristics	520
16.3.3	Equipment and Tools	521
16.3.4	Physical Environment	524
16.3.5	Social/Psychological Environment	526
16.3.6	Human Error	527
16.4	Hazard Identification and Control	531
16.4.1	Hazard Criticality and Risk	532
16.4.2	Hazard Identification	532
16.4.3	Hazard Controls	535
16.5	Safety Management	537
16.5.1	Safety Programs	537
16.5.2	Accident and Incident Investigation	539
16.5.3	Safety Regulators	540
16.6	Risk-taking and Warnings	540
16.6.1	Risk-taking as a Decision Process	540
16.6.2	Written Warnings and Warning Labels	542
16.7	Summary	544
	Questions	546
17	Job Design, Selection, and Training	547
17.1	Job Design	549
17.2	Personnel Selection	553
17.2.1	Basics of Selection	553

17.2.2 Selection Tests and Procedures	555
17.3 Performance Support and Job Aids	558
17.4 Supporting People with Disabilities	561
17.5 Training	562
17.5.1 Learning and Expertise	562
17.5.2 Methods for Enhancing Training	565
17.5.3 Transfer of Training and Simulation	572
17.5.4 On-the-Job and Embedded Training . . .	574
17.6 Training Program Design	574
17.6.1 A Training Program Design Model	575
17.7 Summary	578
Questions	579
18 Organizational Design	581
18.1 System and Organizational Characteristics	583
18.1.1 Organizational Design	584
18.1.2 Organizational Culture and Social Norms	585
18.2 Groups and Teams	586
18.2.1 Characteristics of Groups, Teams, and Crews	587
18.2.2 Group Performance	587
18.2.3 Team Performance	588
18.2.4 Team Training	593
18.3 Computer-supported Cooperative Work and Network Enabled Interactions	595
18.3.1 Decision Making Using Groupware	596
18.3.2 Computer-supported Team Performance	596
18.3.3 Difficulties of Remote Collaboration . . .	598
18.4 Macroergonomics and Work System Design	599
18.5 Summary	602
Questions	604
Bibliography	605
Figure credits	657
Index	659