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9th Tübingen Perception Conference

TWK 2006, Tübingen, Germany, 3rd–5th March 2006
Proceedings

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Preface

This year, TWK will move from the downtown “Kupferbau” building to the University Science Campus “Auf der Morgenstelle”. This is due to a number of construction works going on at different university buildings, so that the Kupferbau was not available. We think, however, that the Morgenstelle Lectural Hall Building will prove convenient for the TWK. We have plenty of space for poster boards, a lovely botanical garden just outside, and the University mensa in walking distance.

The symposia once more span a wide range of topics. We start with the integration of visual and vestibular information in a symposium organized by Karl Beykirch and Heinrich Bühlhoff. The symposium on sensory ecology in mammals, organized by Björn Siemers, shows perception in a biological and evolutionary perspective. Finally, the Sunday morning symposium put together by Matthias Weigelt will deal with the perceptual-cognitive mechanisms of action control.

As in all the previous years one central event of the TWK is the extended poster session on Saturday. Altogether we have accepted over 100 posters to be presented at TWK 2006.

The public lecture will be given by Professor Jürgen Wertheimer (Lehrstuhl für Komparatistik/Neue Deutsche Literaturwissenschaft of Tübingen University) who will discuss perception from the perspective of German and comparative literature. Since this talk will be open to the general public, it will be given in German. The title will be: “Wie wirklich ist die Illusion?”

Since the 3rd TWK in 2000 we have awarded a prize for the best poster contributed by an undergraduate or graduate student. In 2005 the poster prize was awarded to Marc Zirnsak of the Universität Münster for his contribution “A Neurocomputational Model of Perisaccadic Compression and Receptive Field Dynamics Based on Oculomotor Feedback”. The prize is a cheque over 500 Euros, donated by the Förderverein für neurowissenschaftliche Forschung, e.V., whose support we gratefully acknowledge.

The Organizing Committee
Tübingen, January 2006

Sponsoring Institutions

Max-Planck-Institut für biologische Kybernetik, Tübingen, Germany
Eberhard-Karls-Universität Tübingen, Germany
Förderverein für neurowissenschaftliche Forschung, e.V.

Local Support Team

As in previous years many assiduous people worked in the background and made this conference possible. **Dagmar Maier**, Heinrich Bühlhoffs secretary, now with 9 years of TWK experience, knew at every point in time which task should be done next. She organized the whole registration, the conference banner, and the name-badges, just to mention a few things. This year she was supported by **Monika Freitag-Schiele**, secretary of Rolf Ulrich. She is responsible for the catering, coffee, lunch and also for the registration desk and parking places.

Felix Wichmann left the organizing committee for private reasons. Fortunately, he was still available for all those little questions.

The administration of the home page was taken care of by **Johannes Thiele**, with technical support from **Jeremy Hill** and **Mirko Thiesen**. **Jeremy Hill** furthermore supervised, compiled and made final corrections to the conference proceedings.

Internet access during the conference is possible thanks to **Heinz Bendele**.

Friday 3rd March 2006

14:00 Registration and hanging of posters

14:55 Welcome

Symposium 1: Vestibular Perception

From Basic to Applied Research

(Karl Beykirch and Heinrich H. Bühlhoff, MPI for Biological Cybernetics, Tübingen)

Symposium to be conducted in English

15:00 **Introduction**

Karl Beykirch (MPI for Biological Cybernetics, Tübingen)

15:10 **Spatial Perception: Multisensory Integration in Extrastriate Visual Cortex**

Dora Angelaki (Washington University, St. Louis)

15:40 **The Role of Time in Vestibular Perception of Self-Motion**

Stefan Glasauer (University of Munich)

16:10 **Visual Vestibular Interactions for Self Motion Estimation**

Stuart Smith (Trinity College, Dublin), John Butler, Karl Beykirch (MPI for Biological Cybernetics, Tübingen) & Heinrich H. Bühlhoff (MPI for Biological Cybernetics, Tübingen)

16:40 Coffee break

17:10 **Postrotatory Vestibular Influences on Visual Processes**

Heiko Hecht (University of Mainz)

17:40 **Investigations Developing a Vestibular Prosthesis**

Daniel M. Merfeld (Harvard University), Wangsong Gong (Harvard University), Jennifer Morrissey (Massachusetts Eye and Ear Infirmary), Csilla Haburcakova (Harvard University) & Richard F. Lewis (Harvard University)

18:10 **Consequences of Visual-Vestibular Interactions in High-Tech Environments**

Willem Bles (TNO Human Factors, Soesterberg), Jelte Bos, Eric Groen & Mark Wentink

Saturday 4th March 2006

Symposium 2: Sensory Ecology in Mammals A Comparative Approach to Mammalian Perception of the World (Björn Siemers, Universität Tübingen)

Symposium to be conducted in English

- 09:00 **Introduction**
Björn Siemers (Universität Tübingen)
- 09:05 **Adaptation of Sensory Systems to the Properties of their Natural Input**
Christoph Kayser (MPI for Biological Cybernetics, Tübingen)
- 09:35 **Sensory Ecology in Foraging Primates**
Nathaniel Dominy (University of California)
- 10:05 **Tactile Perception in Aquatic Mammals**
Guido Dehnhardt (University of Bochum)
- 10:35 Coffee break
- 11:05 **Sensory Ecology of Subterranean Rodents**
Hynek Burda (University of Duisburg-Essen)
- 11:35 **Sensory Ecology of Insect-Eating Bats**
Björn Siemers (University of Tübingen)
- 12:05 **Smelling who Fits: The Role of Olfaction for Mate Choice in Mice and Men**
Dustin Penn (Konrad Lorenz Institute for Ethology, Vienna)
- 12:35 Lunch break

Poster sessions

The posters will be divided into 4 groups. The authors should be present at their poster at least during the time allocated to their group as follows. The poster boards will be marked to indicate which group the poster is in. Note that we have extended the poster session to allow more time at the posters.

- 13:45 Group A
- 14:55 Group B
- 16:05 Group C
- 17:15 Group D
- 18:20 Poster prize to be awarded

Public evening lecture (to be given in German)

- 18:30 **Wie wirklich ist die Illusion?**
Jürgen Wertheimer (Universität Tübingen)
- 20:15 Banquet in the Tübinger Kelter
NB: places are limited. Tickets may be reserved during online registration, and any remaining tickets will be sold at the registration desk.

Sunday 5th March 2006

Symposium 3: Perceptual-Cognitive Mechanisms of Action Control
(Matthias Weigelt, MPI for Human Cognitive and Brain Sciences, Munich)
Symposium to be conducted in English

- 09:00 **Introduction**
Matthias Weigelt (MPI for Human Cognitive and Brain Sciences, Munich)
- 09:10 **Sensory-Motor Control of Grasping Forces: from Experimental Studies to Clinical Application**
Dennis A. Nowak (University of Ulm, Germany)
- 09:40 **Self and Other in the Human Motor System**
Simone Schuetz-Bosbach (University College, London), Bendetta Mancini (University College, London), Salvatore M. Aglioti (University of Rome) & Patrick Haggard (University College London)
- 10:10 **Dorsal and Ventral Processing in the Psychological Refractory Period Paradigm**
Wilfried Kunde (Universität Halle-Wittenberg)
- 10:40 Coffee break
- 11:10 **Fitts' Law under Conditions of Transformation Between Movement Space and Visual Space**
Martina Rieger (MPI for Human Cognitive and Brain Sciences, Munich) & Wolfgang Prinz (MPI for Cognitive and Brain Sciences, Leipzig)
- 11:40 **Task-Specific Action-Effect Binding**
Dieter Nattkemper (Humboldt-Universität, Berlin), Peter A. Frensch (Humboldt-Universität, Berlin) & Michael Ziessler (University of Sunderland)
- 12:10 **Preparing Two Actions: The Influence of Actions Goals on the Production of Bimanual Responses**
Matthias Weigelt (MPI für Kognitions- und Neurowissenschaften, Munich)
- 12:40 Closing discussion, removal of posters, end of conference

Contents

Public evening lecture (to be given in German)	17
J. Wertheimer:	
<i>Wie wirklich ist die Illusion ?</i>	18
Symposium 1: Vestibular Perception	
From Basic to Applied Research	19
D. Angelaki:	
<i>Spatial Perception: Multisensory Integration in Extrastriate Visual Cortex</i>	20
S. Glasauer:	
<i>The Role of Time in Vestibular Perception of Self-Motion</i>	21
S. Smith, J. Butler et al.:	
<i>Visual Vestibular Interactions for Self Motion Estimation</i>	22
H. Hecht:	
<i>Postrotatory Vestibular Influences on Visual Processes</i>	23
D. Merfeld, W. Gong et al.:	
<i>Investigations Developing a Vestibular Prosthesis</i>	24
W. Bles, J. Bos et al.:	
<i>Consequences of Visual-Vestibular Interactions in High-Tech Environments</i>	25
Symposium 2: Sensory Ecology in Mammals	
A Comparative Approach to Mammalian Perception of the World	27
C. Kayser:	
<i>Adaptation of Sensory Systems to the Properties of their Natural Input</i>	28
N. Dominy:	
<i>Sensory Ecology in Foraging Primates</i>	29
G. Dehnhardt:	
<i>Tactile Perception in Aquatic Mammals</i>	30
H. Burda:	
<i>Sensory Ecology of Subterranean Rodents</i>	31
B. Siemers:	
<i>Sensory Ecology of Insect-Eating Bats</i>	32
D. Penn:	
<i>Smelling who Fits: The Role of Olfaction for Mate Choice in Mice and Men</i>	33
Symposium 3: Perceptual-Cognitive Mechanisms of Action Control	35
D. A. Nowak:	
<i>Sensory-Motor Control of Grasping Forces: from Experimental Studies to Clinical Application</i>	36

S. Schuetz-Bosbach, B. Mancini et al.:	
<i>Self and Other in the Human Motor System</i>	37
W. Kunde:	
<i>Dorsal and Ventral Processing in the Psychological Refractory Period Paradigm</i>	38
M. Rieger & W. Prinz:	
<i>Fitts' Law under Conditions of Transformation Between Movement Space and Visual Space</i>	39
D. Nattkemper, P. A. Frensch & M. Ziessler:	
<i>Task-Specific Action-Effect Binding</i>	40
M. Weigelt:	
<i>Preparing Two Actions: The Influence of Actions Goals on the Production of Bimanual Responses</i>	41
Animal Senses	43
K. Koselj, H.-U. Schnitzler & B. Siemers:	
<i>Adaptive Prey Selection Strategy in Echolocating Horseshoe Bats</i>	44
M. Meln, A. Denzinger & H.-U. Schnitzler:	
<i>Echolocation Behavior of Myotis Nattereri while Approaching Stationary and Moving Targets</i>	45
Attention and Awareness	47
K. M. Bausenhardt, B. Rolke & R. Ulrich:	
<i>Temporal Preparation Increases Perceived Duration: Evidence from Reaction Times to Stimulus Onset and Offset</i>	48
D. Bratzke, B. Rolke et al.:	
<i>Dual-Task Interference During Response Execution: Evidence from the Psychological Refractory Period Paradigm</i>	49
V. Conrad, Z. Kourtzi & A. Welchman:	
<i>Breaking the Stability of Perceptual Instability: Adaptation and Priming in Ambiguous Figure Perception</i>	50
M. Grosjean & G. Rinkenauer:	
<i>Effects of Redundant Visual Stimuli Within and Across Depth Planes</i>	51
G. Rinkenauer & M. Grosjean:	
<i>Focused Attention in Three-Dimensional Space: An Eriksen-Flanker Study</i>	52
B. Rolke & P. Hofmann:	
<i>Temporal Uncertainty Degrades Perceptual Processing</i>	53
T. Schmidt & A. Seydell:	
<i>Modulation of Cortical Feedforward Dynamics by Endogenous and Exogenous Attention</i>	54
K. Schwarzfischer:	
<i>Systemsemiotic Predictive of Visual Recognition</i>	55
A. Seydell & T. Schmidt:	
<i>Response Priming with Illusory Contour Figures</i>	56
D. Vorberg:	
<i>Do Reversed Effects in Masked Priming Reflect Disguised Facilitation Rather than Inhibition?</i>	57

Contents	11
Auditory Perception	59
S. Krüger & J. Lukas:	
<i>The Perception of Relative Pitch of Octave-Complex Tones in a Dichotic Listening Experiment: Central or Peripheral Mechanisms.</i>	60
T. Lennert & W. Lutzenberger:	
<i>Decision-Related Processes in Auditory Spatial and Pattern Recognition</i>	61
W. Pflästerer & H.-U. Schnitzler:	
<i>Performance of Myotis Nattereri Foraging near Vegetation</i>	62
H. Schröter, R. Ulrich & J. Miller:	
<i>Auditory Redundancy Gain</i>	63
Computer Vision and Robotics	65
P. Biber, S. Fleck & W. Strasser:	
<i>The Wägele: A Mobile Platform for Acquisition of 3D Models of Indoor and Outdoor Environments</i>	66
S. Fleck, F. Busch et al.:	
<i>Omnidirectional Stereo Based 3D Model Acquisition on the Wägele Platform using Graph Cuts</i>	67
W. Hübner & H. A. Mallot:	
<i>An Affine Invariant Scene-Graph for Object Recognition and Navigation</i>	68
J. Schultz & F. de Vignemont:	
<i>A Model of Theory-Of-Mind Based on Action Prediction</i>	69
Multimodal Interactions: Sensory Integration	71
I. Bühlhoff & F. N. Newell:	
<i>Face Distinctiveness can be Modulated by Cross-Modal Interaction with Auditory Stimuli</i>	72
H. Colonius & A. Diederich:	
<i>Why Two “Distracters” are Better than One: Modelling the Effect of Non-Target Auditory and Tactile Stimuli on Visual Saccadic Reaction Time</i>	73
T. Cooke, F. Jäkel et al.:	
<i>Exploring Connections Between Similarity and Categorization using Vision and Touch</i>	74
A. Diederich & H. Colonius:	
<i>Separating Multisensory Integration from Unspecific Warning Effects in Saccadic Reaction Time</i>	75
K. Drewing, B. Jovanovic & V. Christen:	
<i>Visuo-Haptic Binding in Young Adults and 5-Year-Old Children</i>	76
I. Frissen & M. O. Ernst:	
<i>Visual Influence on Tactile Localization</i>	77
H. Helbig, E. Ricciardi et al.:	
<i>Integration of Shape Information from Vision and Touch: Optimal Perception and Neural Correlates</i>	78
F. N. Newell, C. Lange et al.:	
<i>Haptic Exploration Behavior During Bimodal Object Recognition</i>	79
D. Peters, W. Hübner & H. A. Mallot:	
<i>Reinforcement Learning of Automatic Integration of Navigation Strategies Based on an Infomax Principle</i>	80

Multimodal Interactions: Sensory-Motor Integration	81
U. Biber & U. J. Ilg: <i>Initiation of Smooth-Pursuit Eye Movements by Real and Illusionary Contours</i>	82
S. Freyberg & U. J. Ilg: <i>Frontal Field Activity Represents Anticipatory Eye Movements and Behavioral Task Segmentation</i>	83
C. Hesse & V. H. Franz: <i>The Use of Visual Memory for Grasping</i>	84
A. Mandler & U. J. Ilg: <i>Eye Movements in Reading—Scrolling Text Compared to Static Text.</i>	85
R. Ulrich, R. Fernandez et al.: <i>The Psychological Refractory Period: Is Response Execution Part of the Central Processing Bottleneck?</i>	86
M. P. Vitello & M. O. Ernst: <i>Active Arm Movement Impairs Tactile Discrimination Performance</i>	87
J. Zwickel, M. Grosjean & W. Prinz: <i>On the Time Course of a Specific Interference Effect of Action on Perception</i>	88
Natural Image Statistics	89
M. Bethge: <i>Factorial Coding of Natural Images: How Effective are Linear Models in Removing Higher-Order Dependencies?</i>	90
M. Dorr, M. Böhme et al.: <i>Visibility of Temporal Blur in Natural and in Synthetic Scenes</i>	91
J. Drewes, F. A. Wichmann & K. R. Gegenfurtner: <i>Classification of Natural Scenes: Critical Features Revisited</i>	92
R. W. Fleming: <i>Manifesto for the Study of Material Perception</i>	93
L. Gerstmayr & H. A. Mallot: <i>Image Statistics and Optimal Edge Detection</i>	94
Perception of Time	95
K. Kirschfeld: <i>The Hierarchy of Brain and Mind</i>	96
B. Rigamonti & D. Long: <i>Influence of Vestibular Information on Time Perception</i>	97
Perceptual Development	99
A. Frank, R. Sireteanu & S. Kiko: <i>Development of the Detection of Ambiguities in Vision and Speech</i>	100
V. Ressel, M. Wilke et al.: <i>Language Lateralization in Children using Magnetoencephalography: a New Task to Investigate Hemispheric Dominance</i>	101
Perceptual Neuroscience	103
A. Hodzic, L. Muckli et al.: <i>Identity Related Responses in the Human Extrastriate Body Area: An fMRI Study</i>	104

J. Rüter, M. Himmelbach & H.-O. Karnath: <i>Visual Form Agnosia after Medial Occipital Temporal Lesions Sparing LOC.</i>	105
H. Turesson & A. Schüz: <i>Cortico-Cortical Connectivity: Measurements on Distant Axonal Arbores of Pyramidal Cells in the Mouse Neocortex</i>	106
Tactile Perception	107
J. Trojan, A. Stolle et al.: <i>Psychophysical Assessment of Distortions in Heat/pain Somatotopy after Sensitisation of the Skin</i>	108
A. Wühle, J. Rüter et al.: <i>An MEG Paradigm to Study the Cortical Processing of Near-Threshold Tactile Stimuli</i>	109
Visual Cognition: General	111
B. Garsoffky, M. Huff & S. Schwan: <i>The Influence of Camera Height on the Recognition Performance of a Dynamic Scene</i>	112
G. Hardiess, S. Gillner & H. A. Mallot: <i>Head and Eye Movements in a Widespread Stimulus Comparative Search Paradigm</i>	113
M. Huff, B. Garsoffky & S. Schwan: <i>The Verbal Overshadowing of Dynamic Scenes: The Influence of Source Confusion.</i>	114
Q. C. Vuong & I. M. Thornton: <i>The Role of Motion in Natural Scene Processing Revealed by Visual Search</i>	115
Visual Cognition: Objects and Faces	117
L. Chuang, Q. C. Vuong et al.: <i>Recognizing Dynamic Object Across Viewpoints</i>	118
J. Fischer, D. Cunningham et al.: <i>Virtual or Real? Judging The Realism of Objects in Stylized Augmented Environments</i>	119
E. Huberle, K. Seymour et al.: <i>Involvement of the Temporo-Parieto-Occipital Junction (TPOJ) in Global Gestalt Perception</i>	120
K. S. Pilz, H. H. Bühlhoff & I. M. Thornton: <i>Internal and External Facial Features Differentially Bias Person Recognition—An Approach using Animation Techniques</i>	121
R. Schönenberger & D. Long: <i>Mental Rotation of Human Figures in the Picture and Depth Plane</i>	122
U. Weidenbacher, P. Bayerl & H. Neumann: <i>Generation of Sketch-Like Feature Encodings in Oriented Faces—A Neural Model</i>	123
Visual Cognition: Space Perception and Navigation	125
N. Ehbauer, D. Seffer et al.: <i>Path Planning and Optimization in the Traveling Salesman Problem</i>	126

T. Meilinger, A. Widiger et al.:	
<i>Verbal, Visual and Spatial Memory in Wayfinding</i>	127
M. M. Popp, E. Neidhard & M. Lehmann:	
<i>Quality and Barrier-Effects in Pointing in Reality and in VR of “Kindergarten”</i> <i>Childs</i>	128
J. Saez Pons & H. A. Mallot:	
<i>Robust Visual Navigation using Optical Flow Fields in Dynamical</i> <i>Environments</i>	129
Visual Perception: Colour	131
A. Bompas:	
<i>Sensorimotor Adaptation in Colour</i>	132
C. Dörre & C. Kaernbach:	
<i>Color Perception of Transparent Substances</i>	133
M. Giesel, T. Hansen & K. R. Gegenfurtner:	
<i>Discrimination of Synthetic Chromatic Distributions which Resemble Natural</i> <i>Distributions</i>	134
K. Hamburger, T. Hansen & K. R. Gegenfurtner:	
<i>Geometric-Optical Illusions at Isoluminance</i>	135
T. Hansen & K. R. Gegenfurtner:	
<i>Statistics of Chromatic Edges in Natural Scenes</i>	136
K. Heier & S. Schultz:	
<i>Increments and Decrements in Color Constancy: A Comparison of Natural</i> <i>Und Artificial Illuminants</i>	137
C. Kaernbach & G. Scheibelhofer:	
<i>A Retinal Phenomenon Occurring while Viewing a Light Spot</i>	138
L. Kaim, T. Hansen & K. R. Gegenfurtner:	
<i>An Interactive Simulation of a Parvocellular Retinal Ganglion Cell</i>	139
S. Klauke & T. Wachtler:	
<i>How Color Induction Depends on Hue Differences Between Stimulus and Sur-</i> <i>round</i>	140
S. Liebe, N. K. Logothetis & G. Rainer:	
<i>The Contribution of Color to Recognition Performance in the Non-Human Pri-</i> <i>mate</i>	141
M. Olkkonen, T. Hansen & K. R. Gegenfurtner:	
<i>Color Constancy for Natural Objects Using Polar Chromatic Adjustment</i>	142
S. Schultz, K. Dörschner & L. T. Maloney:	
<i>Color Constancy and Hue Scaling</i>	143
Visual Perception: Eye Movements	145
Delipetkos, D. I. Braun & K. R. Gegenfurtner:	
<i>Temporal Contrast Sensitivity During Smooth Pursuit Eye Movements</i>	146
U. Haberland & F. Bremmer:	
<i>Saccades Alter Appearance</i>	147
Y. Jin, S. Gillner & H. A. Mallot:	
<i>A Replication of Yarbus’s Study in Dynamic Scenes</i>	148
M. König, W. Jaschinski & G. Rinkenauer:	
<i>Gains in Time for using Head-Up Display: A Study of Vergence Changes</i>	149

K. Königs & F. Bremmer: <i>Localization of Auditory Targets During Optokinetic Nystagmus</i>	150
M. Spering & K. R. Gegenfurtner: <i>Visual Contextual Effects on Smooth Pursuit Eye Movements</i>	151
M. Stritzke, A. Ma-Wyatt & J. Trommershäuser: <i>Changes in Eye-Hand Coordination During Rapid Pointing Movements under Risk</i>	152
T. G. Tanner: <i>Eye Movements in Shape Categorization</i>	153
B. J. White, D. Kerzel & K. R. Gegenfurtner: <i>Saccadic Facilitation with Natural Scene Backgrounds</i>	154
Visual Perception: Motion	155
P. Bayerl & H. Neumann: <i>The Role of Feature Attention in Motion Perception—A Computational Study about the Interplay of Attentional Selection and Mutual Competition</i>	156
J. Billino, F. Bremmer & K. R. Gegenfurtner: <i>Age-Related Differences in Motion Tasks of Different Complexity</i>	157
S. Getzmann & J. Lewald: <i>Localization of Moving Sound</i>	158
M. A. Giese, I. M. Thornton & S. Edelman: <i>Assessment of the Similarity Metrics of Biological Motion Perception</i>	159
M. Lich & F. Bremmer: <i>Oculomotor Functions and Self-Motion Perception in the Elderly</i>	160
L. Omlor, C. L. Roether & M. A. Giese: <i>Unsupervised Learning of Perceptual Important Features in Emotional Body Expressions</i>	161
P. Pretto & A. Chatziastros: <i>Blame the Road Ahead but not the Fog for Speeding</i>	162
C. L. Roether, L. Omlor & M. A. Giese: <i>Optimal Integration of Movement Components for the Visual Recognition of Emotional Body Expressions</i>	163
J. L. Souman & T. C. A. Freeman: <i>Phase Lags and Gain Ratios in Motion Perception During Smooth Pursuit Eye Movements</i>	164
J. Thiele: <i>Do Rats Use Optical Flow for Motion Control ?</i>	165
R. Wolf: <i>The “Stepwise-Constancy Illusion” (SCI): Constancy Performance of Edge Positions in the Peripheric Visual Field is Accomplished in Visible 70ms Steps</i> . . .	166
Visual Perception: Spatial Vision	167
D. Agotai: <i>A Cinematic View of Space. Methodological Reflections on the Research of Spatial Effects</i>	168
M. Hoffmann, P. Seufert & L. Schmidtborn: <i>Identification and Perceptual Relevance of Abnormal Visual Field Representations in Human Albinism</i>	169

S. Klingenhoefer & F. Bremmer:	
<i>Perisaccadic Mislocalization of Visual Targets: From Shift to Compression</i> . . .	170
W. A. Kreiner:	
<i>Size Illusions Caused by Border Lines—Does Blurring Play a Dominant Role?</i>	171
J. S. McDonald & J. Schultz:	
<i>The Visual System's Representation of Natural Images</i>	172
J. Müsseler & S. Stork:	
<i>Localising Moving Stimuli with a Pointing Task and a Relative Judgment Task</i> .	173
F. A. Wichmann & G. B. Henning:	
<i>The Pedestal Effect is Caused by Off-Frequency Looking, not Nonlinear Trans-</i> <i>duction or Contrast Gain-Control</i>	174
Index of Authors	175

Public evening lecture (to be given in German)

Prof. Jürgen Wertheimer
Universität Tübingen

Saturday 4th March 2006

Wie wirklich ist die Illusion ?

Jürgen Wertheimer

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Paul Watzlawicks Frage nach der Realitätshaltigkeit von "Wirklichkeiten" erscheint im Lichte heutiger Erkenntnisse geradezu beruhigend. Denn wann immer am Horizont unserer postmodernen Wahrnehmung ein Horizont der Wirklichkeit aufzutauchen scheint, erweist er sich auf den zweiten Blick als neue Variante einer Simulation, einer anderen Gestalt von Virtualität. Für die Literatur, die bildende Kunst etc. ist dieser Einbruch der Erkenntnisfähigkeit nichts Neues: wo Fiktion, Imitation und Mimesis- Konstrukte die einzige Form der Wirklichkeit darstellen, ist Wirklichkeit seit je ein Produkt kognitiver bzw. emotionaler Prozesse. An diesem Abend soll an einigen Beispielen gezeigt werden, wie eine Kooperation von Natur- und Geisteswissenschaften an diesem Punkt aussehen könnte.

Ausgehend von Nietzsches Aussage, wonach "Wahrheiten Illusionen seien, von denen man vergessen habe, dass sie welche sind" (Über Wahrheit und Lüge im außermoralischen Sinn) wird die Illusion der "freien Wirklichkeitswahrnehmung" einer Revision unterzogen werden: Erinnerungen, Gedächtnisprozesse, Ich-Entwürfe, kollektiv verbindliche Normensysteme gestalten Perzeption und Erkennungs-Prozesse sowohl auf der Text- wie auf der Bildebene: kognitive wie kulturgeschichtliche Ansätze sind dabei eng verzahnt zu denken: Mentale Programme steuern sowohl Bottom-up- wie Top-down- Verarbeitungen. Zugespitzt gesagt: die Außenwelt wird weitgehend von der Innenwelt umgangen. Dies geschieht interessanterweise im Glauben daran, dass die interne Wirklichkeit ein im wesentlichen verbindliches Abbild der externen Wirklichkeit vermitteln würde. Die emotionale beziehungsweise sprachlich-begriffliche Verarbeitung beziehungsweise Simulation von Wirklichkeit geschieht in einem permanenten Wechselspiel des Vergleichens von inneren und äußeren Wirklichkeitsmodellen. Welches in einer gegebenen Situation dominiert, hängt u. a. von den oben genannten Faktoren ab. Literarische Texte spiegeln und reflektieren diese komplexen Prozesse.

Symposium 1

Vestibular Perception

From Basic to Applied Research

Karl Beykirch and Heinrich H. Bülthoff
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Spatial Perception: Multisensory Integration in Extrastriate Visual Cortex

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Spatial perception of our own self-motion represents a strongly multimodal process. For example, the retinal optic flow patterns generated during self-motion constitute a strong cue for heading perception. However, accurate judgments of heading also require integration of visual and nonvisual cues, including vestibular, proprioceptive, and eye movement signals. This sensory integration is complicated by the fact that signals from different modalities may originate in different reference frames (e.g., eye-centered or head-centered). To explore the neural basis of multisensory spatial motion perception, neural activities in area MSTd were probed during a self-motion direction discrimination task within a virtual reality system, where heading was defined by inertial motion in the absence of optic flow (Vestibular condition), optic flow without inertial motion (Visual condition) and congruent combination of inertial motion and optic flow (Combined condition). As the average neuron was much less sensitive than the monkey's spatial perception, appropriate neural pooling is necessary to account for the behavioral spatial sensitivity under the single-cue conditions. Importantly, psychophysical thresholds were modestly, but significantly, improved in the combined compared to either single-cue condition. A similar improvement was also observed in neuronal discrimination thresholds of a subpopulation of congruent MSTd cells. Notably, greater than chance 'choice probabilities', which characterize the trial-to-trial co-variation between neural responses and the animal's choices, were also observed under all three cue conditions. These results suggest a functional coupling between extrastriate visual area MSTd and multisensory integration for spatial motion perceptual decisions.

The Role of Time in Vestibular Perception of Self-Motion

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Vestibular self-motion cues, e.g., signal from the semicircular canals about angular velocity, lead to perception of self-motion and finally of self- displacement. In the case of rotation around an earth-horizontal axis in darkness, angular self-displacement has to be computed from angular velocity by a process called path integration. Studies on path integration commonly assume that velocity and displacement are represented internally, for example by networks like the head direction cell system. The role of time has so far been neglected, since time is usually not considered a variable requiring internal representation. However, physical time must not necessarily coincide with perceptual time. In psychology it is well-known that dual tasks such as mental arithmetic affect the judgement of duration, and thus alter subjective time. In my talk I will present evidence that a dual task also influences the internal representation of space, and that this influence is compatible with a distortion of subjective time. Subjects were asked to estimate their spatial orientation or to reproduce an imposed angular self-motion while doing mental arithmetic. In all experiments in which the spatial representation had to be derived from motion signals, i.e., by path integration, the perceived displacement was influenced by the dual task. Notably, this was also true in comparable experiments on locomotion in darkness. The results support the hypothesis that the observed distortion of subjective space was a consequence of a distorted internal representation of time, rather than due to errors in velocity perception or production. The experiments suggest that 1) there is an internal representation of time even if an estimate of time passed is not explicitly required, and 2) this internal representation of time is used for path integration and thus to derive internal representations of space. In conclusion, I will discuss the consequences of the findings for models of path integration.

Visual Vestibular Interactions for Self Motion Estimation

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Navigation through the environment is a naturally multisensory task involving a coordinated set of sensorimotor processes that encode and compare information from visual, vestibular, proprioceptive, motor-corollary, and cognitive inputs. The extent to which visual information dominates this process is no better demonstrated than by the compelling illusion of self-motion generated in the stationary participant by a large-field visual motion stimuli. The importance of visual inputs for estimation of self-motion direction (heading) was first recognised by Gibson (1950) who postulated that heading could be recovered by locating the focus of expansion (FOE) of the radially expanding optic flow field coincident with forward translation. A number of behavioural studies have subsequently shown that humans are able to estimate their heading to within a few degrees using optic flow and other visual cues. For simple linear translation without eye or head rotations, Warren and Hannon (1988) report accurate discrimination of visual heading direction of about 1.5°. Despite the importance of visual information in such tasks, self-motion also involves stimulation of the vestibular end-organs which provide information about the angular and linear accelerations of the head. Our research has previously shown that humans with intact vestibular function can estimate their direction of linear translation using vestibular cues alone with as much certainty as they do using visual cues. Here we report the results of ongoing investigation of the integration of visual and vestibular cues to self-motion.

Postrotatory Vestibular Influences on Visual Processes

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Unusual vestibular environments become increasingly common. Driving simulators, virtual reality environments, and space travel produce visual- vestibular mismatches caused by unusual, that is mostly inadequate, vestibular stimulation. These mismatches have detrimental effects on visuomotor coordination, however, they are partially overcome by adaptation, which appears to be rather context-specific. In other words, observers who are repeatedly exposed to unusual vestibular environments become vestibular experts. We report two experiments that were designed to take a closer look at the immediate vestibular aftereffects of a brief unusual stimulation in experts and novices. Human observers were passively rotated and their gaze holding ability was assessed objectively by recoding eye movements and subjectively by asking them to rate the magnitude of the experienced autokinetic effect. A loss in gaze holding precision could be demonstrated 30 sec. after rotation. Interestingly, experts showed poorer scores in the objective measure but reported smaller autokinetic effects than did novices.

Investigations Developing a Vestibular Prosthesis

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Disorders of the peripheral vestibular system are relatively common and often result in severely impaired mobility, blurred vision and debilitating attacks of vertigo and motion sickness. Presently, little can be done to resolve these symptoms when they are chronically present. While data are limited, prevalence of profound vestibular problems appears about the same as profound hearing loss. Early research in the area of vestibular neuroprosthetics alongside the success of the cochlear implant, provides hope that providing motion cues via electrical stimulation may eventually help some patients suffering severe vestibular impairment. Conceptually, vestibular prostheses are similar to cochlear implants and consist of 4 principal elements: a power source, motion sensors, a microcontroller, and an electrode. We have developed and tested a vestibular prosthesis that senses yaw angular head velocity and uses this information to modulate the rate of current pulses applied to the vestibular nerve via an electrode chronically. This device has been tested in three species. In squirrel monkeys, the lateral canals were plugged bilaterally and our prosthesis was secured to the head with the angular velocity sensor parallel to the axis of the lateral canals. The stimulating electrode was placed near the ampullary nerve of one lateral canal. When rotated in the dark, the animals responded with an appropriate horizontal vestibulo-ocular reflex (VOR), which adapted over time, providing evidence that the CNS was utilizing the information provided electrically. Data also show that the artificial rotational cue provided by the prosthesis is combined with normal sensory cues measuring the relative orientation of gravity. In other experiments, guinea pigs were provided chronic constant-rate stimulation and responded with a brisk nystagmus that adapted away after about a day. When the stimulation was removed, a brisk nystagmus in the opposite direction was measured, again lasting about a day. These findings demonstrate adaptation to constant-rate stimulation. When the stimulation was alternately turned on and off weekly, the nystagmus response began to decay more rapidly, eventually decaying just a few seconds after the device was turned on or off. This indicates that, with repetitive application of chronic stimulation, the animal learned to adapt rapidly to the present state (on or off) of stimulation. Such “switching” will be important for users of vestibular prosthetics so they don’t feel disoriented when they remove the device to sleep, shower, etc. Finally, in studies with rhesus monkeys, we inserted an electrode into the right posterior canal. We have found that that the application of prosthetic stimulation to a posterior canal yields perceived tilt illusions consistent with predictions for normal semicircular canal stimulation. While all of this preliminary work suggests clinical potential, many neuroengineering and neuroscience questions remain unanswered, and many challenges must be addressed prior to clinical use.

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Consequences of Visual-Vestibular Interactions in High-Tech EnvironmentsWillem Bles,¹ Jelte Bos,² Eric Groen² and Mark Wentink²¹TNO Human Factors, Soesterberg, ²

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High-tech environments often challenge the limits of a properly working human balance system. In this presentation some of these areas will be discussed. Modern architects in the Netherlands, a rather flat country, like to construct with modern technologies buildings that are just not aligned with gravity. Although visually attractive, the perceptual and postural consequences cannot be neglected, especially not in people relying primarily on vision. Obviously, a visual vertical in line with gravity is desired here. Similar observations occur at sea, where the situation may be even worse because of the ship motion. Visual-vestibular interactions during head movements force the naval engineers to design work places such that head movements can be reduced to a minimum. It was also shown in experiments on evacuation from listing ships how these visual-vestibular interactions on attitude perception prevent passengers to behave according to the assumptions that served as a basis for ship design guidelines. Another area of interest is Spatial Disorientation, a significant cause of aircraft accidents, not only in the past, but nowadays as well. These accidents happen because the human equilibrium system is not able to correctly perceive the aircraft motion profile, leading to accidents like CFIT (Controlled Flight into Terrain). Ground based demonstration of the underlying mechanisms like the basic visual-vestibular illusions is one thing, training the pilots how to avoid SD is something else, especially in refresher courses. In this area correct motion cueing is of vital importance. However, it also shows us the restrictions we face right now in motion cueing, the need for systematic scientific data, both for flight simulation and for driving simulation.

Symposium 2

Sensory Ecology in Mammals

A Comparative Approach to Mammalian Perception of the World

Björn Siemers
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Adaptation of Sensory Systems to the Properties of their Natural Input

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Our sensory systems perform pretty successful and fast in processing the complex scenarios of sensory stimuli that we encounter during every day tasks. It seems likely that over evolutionary timescales our senses adapted to the statistical regularities inherent to the every day stimuli that we have to analyze. This leads to the hypothesis that various aspects of sensory processing are ‘optimal’ for extracting information from natural input; vice versa, one should be able to understand the organization of sensory processing given the statistical regularities of natural stimuli and given the right optimization principle. In this talk I will address this question by examining the processing of single neurons in the primary visual cortex, so called simple and complex cells. Recent work showed how the processing of these cells can be understood as efficient and redundancy reducing codes of natural visual features—called sparse and slow feature codes. Especially, by applying these optimality principles to artificial networks processing natural visual scenes, properties of simple and complex cells can be reproduced. Besides vision, other senses perform similar analysis of complex stimuli, posing the question whether different senses can be understood using similar functional principles. Using audition as an example, it can be shown that the same optimality principles deduced from the visual cortex do a good job in explaining the processing of auditory neurons. This suggests that, on a more abstract level, different sensory systems perform similar operations that are defined by certain optimality criteria and the statistical properties of natural sensory stimuli. Especially, the early sensory processing in different sensory systems seems to be based on a small set of common computational principles that links properties of the outside world to properties of neuronal circuits.

Sensory Ecology in Foraging Primates

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All primates have two aims, survival and reproduction. To achieve these aims primates must acquire and process information about objects in their environment, such as predators, food, and mates. The physical and chemical properties of such targets are predicted to exert a strong selective pressure on the sensory systems of primates. The senses of primates are quite different from those of other mammals, and the senses of humans can be quite different from other primates. To achieve a deeper understanding of how and why human senses evolved, it is important to quantify the sensitivity of particular sense receptors, to observe how primates acquire environmental information, and to model the extent to which senses are optimized to discriminate vital targets from distracting background information. Because primates are largely herbivorous, consuming various quantities of fruits and leaves, I will present data on the physical and chemical properties of fruits and leaves and discuss the optimality of visual, haptic, and olfactory modalities to discerning and selecting them.

Tactile Perception in Aquatic Mammals

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Tactile perception in aquatic mammals can be considered to be primarily a function of their vibrissae, colloquial called “whiskers”. The vibrissal follicles of pinnipeds are densely innervated mechanosensory organs. The number of nerve fibres entering a single follicle exceeds that calculated for rats and cats by a factor of ten. This difference in innervation already indicates that the vibrissal system is of special importance for aquatic mammals. However, the functional significance of the vibrissal system remained obscure for a long time. Our psychophysical experiments have shown that seals can use their vibrissae as a haptic sensory system (active touch) involving a physical contact of the vibrissae to objects in the environment. As blind seals are well nourished throughout the year this suggests the potential significance of haptic vibrissal information for the detection and identification of benthic prey. The question remains whether vibrissae could also provide sensory information for the detection of pelagic fish. In the aquatic environment, one utilizable source of sensory information consists of water disturbances, inevitably caused by any moving organisms. Consequently, hydrodynamic sensory systems, like the lateral line of fish, have evolved many times in aquatic animals. For the vibrissal system of harbour seals this function as a hydrodynamic receptor system has been demonstrated with a technique commonly used to study the fish lateral line. In terms of particle displacement the seal responded to water movements < 1 m at 50 Hz. The shape of the tuning curve obtained for the seal characterizes the vibrissae as a hydrodynamic receptor system with a spectral sensitivity well tuned to the frequency range of fish generated water movements. Although hydrodynamic information is assumed to be important only in the vicinity of the receiving animal, the wakes of fishes persist for several minutes, thus representing trackable hydrodynamic trails of considerable length. Using a miniature submarine for the generation of hydrodynamic trails we have shown that a blindfolded harbour seal can use its whiskers to detect and accurately track such trails. These results demonstrate for the first time that hydrodynamic information can be used for long-distance object location, thus establishing a new system for spatial orientation in the aquatic environment that might help explain successful feeding of pinnipeds in dark and murky waters.

Sensory Ecology of Subterranean Rodents

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Across the globe, representatives of several rodent families have adapted for life in self-constructed underground burrow systems, where they forage and spend most of their lives. The subterranean environment is restricting communicative signals and is deprived of most spatial and time orientation cues available aboveground. Since burrowing is energetically demanding, it is expected that energetically costly sensory organs and brain centres, which are of no use underground, should regress. On the other hand, subterranean rodents, like other animals, must find and recognize their food and mates, be warned of danger, orientate in time and space. We may expect that extracting the necessary information from a dark, monotonous, deprived sensory environment require unique and specific sensory abilities. Thus, among “exotic senses”, magnetic compass directional orientation or seismic communication were described in some species of subterranean rodents. Living in darkness, subterranean mammals seem to be predestined to rely on audition for alertness and communication. Indeed, hearing represents the most intensively studied sense in subterranean mammals. Studies of burrow acoustics revealed that in burrows airborne sounds of 400–800 Hz propagated best whereas lower and higher frequencies were effectively attenuated. Concordantly, hearing and vocalization in subterranean mammals studied to date are characterized by a restricted frequency range tuned to low frequencies (0.5–4 kHz). All audiograms reveal low hearing sensitivity. Middle and inner ears show a large degree of morphological convergence. Morpho-functional analyses classify the ear of subterranean mammals as a low frequency, low sensitivity device. Recently, we have shown that low-frequency sounds (200–800 Hz) in burrows are not only least attenuated, yet their intensity may be also amplified (up to 4-times over 1 m). Hearing and vocalization range, and their morphological substrate have thus in the course of evolution become tuned to frequencies, which are available and biologically significant. Hearing sensitivity has become reduced to avoid over-stimulation of the ear in their natural environment. Audiological studies of animals taken out of their natural sensory environment may thus lead to false conclusions regarding hearing sensitivity. On the other hand, visual system reveals less convergence among subterranean rodents. The eyes are quantitatively and qualitatively reduced in spalacines, only quantitatively but not qualitatively reduced in bathyergids, and rather well developed in octodontids and geomyids. Dramatic differences can be found in counts, distribution of rods and cones of particular types. Real visual capacities and the role of vision are unknown in most of the species of subterranean mammals.

Sensory Ecology of Insect-Eating Bats

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The more than one thousand species of bat evolved an amazing diversity of sensory ecologies, providing them perceptual access to food in a wide range of niches. In this talk, I will focus on bats adapted to foraging for arthropods in three-dimensional forest environments. Whereas flying insects in mid-air are easy targets for echolocating bats, it is very difficult to distinguish an insect echo amongst overlapping background echoes from leaves or other clutter. Different ecotypes and phylogenetic lineages of bats evolved different sensory solutions to this ‘clutter problem’, enabling them to detect and select their food in or close to vegetation. The talk will explore the role that sensory ecology plays for prey selection within a species and for resource partitioning between species. I will show that the specific sensory access to prey and prey conspicuousness can passively limit food selection in bats. From a theoretical perspective, it is evident that sensory limitation is the first step in a prey selection process, while active optimal foraging decisions can only be the second step. The evolutionary adaptation of sensory systems to a food niche can render species specialists for certain prey from an ecological viewpoint, although the individuals may largely feed opportunistically on every prey item they detect; resolving the apparent paradox of a specialized predator acting as an opportunistic forager. While sensory constraints might account for a fair amount of the prey selectivity reported for bats, it is likely that at least some bat species are able to actively select among prey perceive and recent experimental data indicate that they do so. A number of studies on closely related animal species have identified morphological differences that lead to differentiation in their mechanical access to food; including the classic case of Darwin’s finches with differently sized and shaped beaks. Less attention has been paid to interspecific differences in the senses used by animals to detect food and their role in promoting resource partitioning within foraging guilds. If a given prey type is easily detectable by one predator species but not by another, this would lead to the same prey being differentially available even if the two predators foraged in the same microhabitat. I will present behavioral experiments and field data suggesting that closely related, potentially competing bat species indeed differ in their sensory access to prey and experience reduced food niche overlap. These data support the hypothesis that sensory ecology might play an important role for niche differentiation.

Smelling who Fits: The Role of Olfaction for Mate Choice in Mice and Men

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Most mammals are visually drab, and males do not have the colorful displays found in birds or fish, yet they have evolved complex mixtures of pheromones and other chemical signals to intimidate rivals and attract mates. Chemical signals convey much information about an individual, including their species, sex, individuality, social status, and health. Moreover, odor cues are also used to assess the genetic quality and compatibility of potential mates (e.g., species recognition, inbreeding avoidance, and perhaps optimizing offspring immunogenetics). Mating preferences for genetic compatibility appear to involve the highly polymorphic genes of the major histocompatibility complex (MHC), which control specific immune recognition of pathogens. MHC genes also influence odor somehow, and some studies have found evidence for MHC-disassortative mating preferences, which could function to produce disease-resistant offspring, avoid inbreeding, or both. I will provide an overview of studies on MHC-dependent mating preferences, emphasizing chemosensory mechanisms, and recent results from a large, multidisciplinary project in which we are using novel methods from quantitative analytical chemistry (SBSE/GC-MS) to identify volatile compounds in mice and humans that convey individual odor signatures and MHC-identity.

Symposium 3

Perceptual-Cognitive Mechanisms of Action Control

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Sensory-Motor Control of Grasping Forces: from Experimental Studies to Clinical Application

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Skilled control of grasping forces involves different modes of control which rely on prediction and sensory feedback to different extents. When we handle objects in the environment that exhibit stable properties, predictive control mechanisms are effectively exploited. For example, when the load of a hand-held object is increased by a self generated action—such as moving the arm during a transport movement—grip force increases in parallel with load force without an obvious time delay. In addition, we usually establish a memory link between the mechanical properties of a particular object and the grasping forces necessary for its manipulation. When, on the other hand, we handle objects with unpredictable behaviour—like holding a dog's leash—sensory feedback provides the most useful source to signal a change in load with the consequence that grasping forces tend to lag behind load. The control of grasping forces has been extensively studied in healthy subjects within the last decade, however, the detailed neural mechanisms underlying both predictive and reactive force control remain widely unknown. In recent years, an increasing amount of lesion data obtained from subjects with various neurological disorders has been gathered and shades some more light onto this issue. Given the well established knowledge on the behavioural aspects of healthy grip force control, there have been several fruitful demonstrations that the investigation of grasping forces is an objective measure for the evaluation of deficient sensory-motor function of the hand in the clinical setting. At present, the investigation of grasping forces is used to assess the sensory-motor deficit due to various neurological disorders and to guide individual pharmacological, surgical and rehabilitative treatment strategies. In psychiatry, the method has currently been established to monitor extrapyramidal side effects due to modern antipsychotic therapy in schizophrenia.

Self and Other in the Human Motor System

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Watching a rubber hand being touched synchronously with one's own unseen hand causes an illusion that the rubber hand is part of one's body. The 'Rubber hand illusion' (RHI) provides a useful experimental method to study the subjective sense of one's body. The sense of bodily self involves a sensory aspect of ownership of sensations, and a motor aspect of agency over one's body. The relation between these two is poorly understood. We therefore investigated whether the sensory experience of ownership generated by RHI can influence the motor system. Subjects observed the index finger of a "rubber hand" (actually an experimenter's hand) being stroked, while feeling identical, synchronous or asynchronous tactile stroking of their own unseen index finger. This caused the subject to feel that the experimenter's hand was part of their own body only in the synchronous condition. During the stroking procedure, the index finger of the experimenter's hand occasionally and unpredictably made index finger movements. To investigate whether the RHI influenced the subject's motor system, we compared motor evoked potentials (MEPs) to Transcranial Magnetic Stimulation recorded at the time of these observed actions with control MEPs recorded when the experimenter's hand was at rest. We found that observed movements of the experimenter's hand facilitated the subjects' own motor system only when the experimenter's hand was not linked to the subject's own body. This suggests that observing the actions of others facilitates the observer's motor system, while observing one's own actions does not.

Dorsal and Ventral Processing in the Psychological Refractory Period Paradigm

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It has been suggested that visual processing proceeds along two anatomically and functionally distinct pathways. A dorsal pathway which mediates control of action (such as grasping an object) and a ventral pathway which mediates conscious perception. Processing along the dorsal pathway is assumed to be fast and automatic, whereas processing along the ventral pathway is supposed to be slow and controlled. In the present study we investigated the proposed functional differences of these modes of processing in a dual-task situation. Participants performed a choice reaction task and concurrently either grasped an object (dorsal task) or judged an object's width (ventral task). Both, dorsal and ventral tasks were subject to massive dual-task interference. In particular the results showed that processing along the dorsal pathway is much less automatic than often suggested. Altogether the results coincide with recent observations which suggest that the differences in ventral and dorsal processing are less evident in normal healthy adults than in neurological patients.

Fitts' Law under Conditions of Transformation Between Movement Space and Visual Space

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Does Fitts' law hold when different transformations between movement space and visual space are introduced? In Experiment 1 participants carried out continuous vertical reversal movements. Movement amplitude (12 cm), target width (0.4 cm) and therefore index of difficulty (5.91) were equal for all conditions. Nine different gain conditions were conducted in different blocks. According to Fitts' law movement times should be equal in all conditions. However, results showed that movements with higher gain were slower than movements with lower gain. The results therefore indicate that extracorporeal space has an effect on movement kinematics and that Fitts' law does not hold across different transformations between movement space and visual space. In further experiments influencing this effect factors (index of difficulty, size of transformation) were investigated.

Task-Specific Action-Effect BindingDieter Nattkemper,¹ Peter A. Frensch¹ and Michael Ziessler²¹Humboldt-Universität, Berlin, ²University of Sunderland

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The ideomotor principle holds that intentional actions are controlled by some anticipatory representation of intended and expected action effects. According to this idea, voluntary actions are planned and executed in terms of effect-codes that bind features of actions and features of desired goals. Recent findings indicate that the mechanisms being responsible for the acquisition of action-effect structures are modulated by intention and selectively bind features of intended effects to features of the actions that bring these effects about. If this is a reasonable notion one may suspect that features of the situational context within which particular actions produce particular effects are incorporated into the binding, too. We studied this issue in experiments where participants were required to switch between two tasks. Both tasks required the same responses, i.e. participants executed the very same responses to perform either task. In the present experiments we simply added different, task irrelevant action effects depending on which task had to be performed. If action-effect codes are task-specific and if these codes do play a role in action planning different effect codes should be activated in the context of the two tasks. Results indicate that action-effect binding operates task-specifically when identical actions effectuate different events depending on the task at hand, and they indicate that task switching may include immediate effect-code switching under certain circumstances.

Preparing Two Actions: The Influence of Actions Goals on the Production of Bimanual Responses

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The dexterity of our two hands is strongly affected by a coalition of constraints—whether perceptual, cognitive, neural, and/or neuromuscular—enslaving the coordinative system. Much research has been devoted to investigate these constraints at the neural and neuromuscular level. Recently, however, constraints at the perceptual and cognitive level have gained considerable attraction, where the influence of perceptual effects and action goals on movement coordination has been the focus of research. We investigated the control of goal-directed actions in a series of experiments involving bimanual reaching, bimanual object manipulation, and bimanual end-state comfort. The results show that bimanual coordination is constraint by the similarity action goals rather than by properties inherent in the neuromuscular system that carries out these goal-directed actions. Thereby, action goals can relate to body-intrinsic states or body-extrinsic states according to the actor's current intentions. We conclude that movement planning is constrained by action goals, but largely unaffected by the type of motor actions necessary to achieve these goals.

Animal Senses

Adaptive Prey Selection Strategy in Echolocating Horseshoe Bats

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Several insectivorous bat species have been shown to feed selectively, i.e. prey on arthropod taxa in proportions different from their relative abundances in the bats' habitat. However, until now it has not been clear whether this selectivity is only an outcome of sensory and ecological limitations on foraging bats or also of active, cognitive decision making. In this study, we used horseshoe bats as a model to experimentally investigate active prey selection. Horseshoe bats possess a highly specialized auditory system, including the so-called acoustic fovea, that enables them to recognize and discriminate fluttering targets (e. g., flying insects). We trained seven adult horseshoe bats to forage in a semi-automated setup. We used glint machines (computer controlled propellers) to mimic fluttering insects of different size and profitability to the bats. Flights towards a slowly rotating large-winged glint machine were rewarded with large mealworms, and flights towards a rapidly rotating small-winged glint machine with small ones. All prey items were presented sequentially. We varied average time intervals between successive presentations and proportion of large and small prey among experimental sessions. The results corroborate predictions of an optimal foraging model. In the sessions with a low encounter rate of large prey, bats foraged unselectively, whereas they specialized on large prey in the sessions in which this prey type was presented frequently. The degree of selectivity was best correlated with the encounter rate of large prey and increased steeply around a threshold value. These results show that the bats were able to detect both types of fluttering targets and connect the fluttering cues to the prey size and profitability. They actively decided whether to eat or reject a prey item, and rapidly adapted their foraging strategy to the changing environment. To study how the bats judge their flight costs, we increased the distance to the targets, and to study how the bats evaluate energy gain and time costs of handling prey, we used two different mealworm sizes for the large prey class. Our data provide the first experimental evidence for active prey selection in bats. They further demonstrate the adaptive value of the horseshoe bats' specialized auditory system connected to cognitive decision making mechanisms in a foraging context.

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Echolocation Behavior of *Myotis Nattereri* while Approaching Stationary and Moving Targets

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The echolocation behavior of bats approaching a specific target (e.g. an insect or a landing site) is characterized by a decrease of pulse duration and pulse interval and an increase in bandwidth. In aerial/trawling foragers the approach sequence ends with a distinct terminal group (buzz II) with very short signals and pulse intervals close to the moving prey. This group is missing in gleaning bats when they approach a stationary site with prey. The approach behavior of aerial/trawling foragers to stationary targets like landing sites has not been investigated yet. Therefore we studied the echolocation behavior of Natterer's bats when approaching either a stationary or a moving target and compared both situations. We trained the bats to land on a stationary vertical platform, and to catch a tethered mealworm moving in the air. For the 3D reconstruction of the bat's trajectory we used two video cameras which were synchronized with sound recording equipment. When closing in on the stationary landing site and on the moving mealworm *M. nattereri* decreased pulse duration and pulse interval. Furthermore, the best frequency tended to increase when the bats were near the target. However, during approach no clear increase in bandwidth was observed. A distinct buzz II was always present when bats pursued the mealworms. Sometimes a shorter buzz II was also emitted when bats approached the landing site. The observed differences may indicate that the distinct buzz II is an adaptation for the pursuit of moving targets which was developed later in evolution.

SFB 550, DAAD

Attention and Awareness

Temporal Preparation Increases Perceived Duration: Evidence from Reaction Times to Stimulus Onset and Offset

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Recent studies suggest that temporal preparation prolongs the perceived duration of a visual stimulus. According to one explanation, this effect reflects a prolonged perceptual persistence of the internal stimulus representation when the subject can precisely predict the stimulus. This prolonged perceptual persistence, however, might be due to a speeded stimulus detection. The present experiment examines whether temporal preparation provokes not only a speeded detection of stimulus onset but also a speeded detection of stimulus offset. Participants were instructed to react as fast as possible to either the appearance of a visual response stimulus (onset condition) or to its disappearance (offset condition). Temporal preparation was manipulated by employing two different levels of foreperiod duration, i.e., the time interval between the occurrence of a warning signal and the response stimulus. As expected, reaction time (RT) was shorter when subjects were able to predict the temporal occurrence of the stimulus event more accurately (i.e., when the foreperiod was short), indicating a higher level of temporal preparation with the shorter foreperiod. Crucially, while onset and offset RT did not differ in the long foreperiod condition, onset RT was shorter than offset RT in the short foreperiod condition. This result suggests a prolonged perceptual persistence associated with high temporal preparation and thus strengthens the notion that temporal preparation increases the perceived duration of a stimulus.

Dual-Task Interference During Response Execution: Evidence from the Psychological Refractory Period Paradigm

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When participants perform two temporally overlapping reaction time tasks, reaction time (RT₂) to the second stimulus increases as stimulus-onset asynchrony (SOA) between the first and second stimulus is decreased. According to the central bottleneck model (CBM), this dual-task interference effect arises because central processes can only select one response at a time. As a result, the response for the second task cannot be selected before the selection of the first response has been finished. According to this standard explanation of this dual-task interference, however, motor processing (e.g., response execution) between both tasks should not interfere. The present study tested the validity of this additional assumption. Thus, we manipulated the duration of response execution in Task 1. Task 1 required either a single keypress or a sequence of three consecutive keypresses, while Task 2 always required the same vocal response. The results revealed an increase of RT₂ in both conditions as SOA decreased, which is in accordance with the CBM. Crucially, however, prolonged response execution of Task 1 produced an additional increase in RT₂. This result argues for an additional bottleneck at the level of motor execution.

Breaking the Stability of Perceptual Instability: Adaptation and Priming in Ambiguous Figure Perception

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Ambiguous figure reversal involves a neural mechanism that limits the number of perceptual organizations that can be consciously experienced at a given moment. So how can perceptual experience be stable and continuous in the presence of alternative interpretations of the same physical stimulus? Recent demonstrations using bistable stimuli such as the Necker cube have revealed that repetitive intermittent presentation leads to a stabilization of the percept [1,2]. According to Gepshtein and Kubovy [3] two temporal processes play an important role in the perception of ambiguous figures: adaptation and hysteresis. In the present study we investigated the effects of reference stimulus duration and interstimulus interval length upon transition probability using ambiguous and unambiguous versions of the Mach Card. On the basis of previous research findings we predicted that long preexposure periods to the reference stimulus lead to adaptation effects. Furthermore we hypothesized that the length of the interstimulus interval between reference and test stimulus affects the subsequent perception of the ambiguous test stimulus. As expected, participants displayed a convex bias in their responses to the ambiguous Mach Card reference stimulus—indicating that they perceived the ambiguous Mach Card as a standing book with the spine pointing towards them. The results of the present experiment suggest that prolonged duration times of ambiguous and unambiguous reference stimuli lead to adaptation effects in the perception of the ambiguous test stimulus. Examining the effects of different interstimulus interval lengths, we demonstrated that short reference stimulus duration times in combination with long interstimulus intervals seem to lock the percept in its present state and the subsequent ambiguous test stimulus will be perceived in the identical configuration. Further analysis will reveal if different adaptation and priming mechanisms are active for convex and concave images, given the inherent tuning of the visual system to convexity. The investigation of these history effects will help us to identify the relative contribution of stimulus-driven and cognitive factors to the perception of ambiguous 3D shapes.

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Effects of Redundant Visual Stimuli Within and Across Depth Planes

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Responses to redundant targets are typically faster than responses to single targets when dividing attention across locations in 2-D space. In the present study, we sought to establish whether such redundancy gains, as they have been labeled, spread across locations in 3-D space. In a go/no-go task, participants were asked to respond to the presence of one or two target stimuli that were stereoscopically presented at a near-depth plane, a far-depth plane, or distributed across the near- and far-depth planes. Evidence for an advantage of redundant targets was found for all depth conditions. However, the size of the redundancy gains did not vary as a function of whether the stimuli appeared exclusively in the near, far, or across both depth planes. The results suggest that redundancy gains spread across locations in 3-D space and, therefore, that attention can be effectively divided across depth planes, at least for the binocular disparities used here.

Focused Attention in Three-Dimensional Space: An Eriksen-Flanker Study

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The influence of depth on focused visual attention was assessed within a three-dimensional display. In contrast to previous studies that have used virtual 3-D displays, the present experiment employed an Eriksen-flanker task within a real 3-D display. Targets and flankers were either presented both at a near-, a far-depth plane, or distributed across the near- and far-depth planes. The visual angle subtended by the stimuli was held constant across the different 3-D locations. As expected, reaction times were longer under incompatible than compatible flanker conditions for all depth combinations. However, unlike the results found with virtual 3-D displays, the compatibility effects were larger when the target was presented at the near- than at the far-depth plane. In addition, reaction times were at their slowest when a near-depth target was accompanied by far-depth incompatible flankers. A possible explanation of this latter finding is that the flankers were perceived as larger at the far- than at the near-depth plane because of the constant visual angles and the depth cues that were available under present conditions. More generally, the present findings suggest that there are differences in the ability to focus attention within virtual and real 3-D space.

Temporal Uncertainty Degrades Perceptual Processing

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When participants are required to react to a stimulus, reaction times (RT) are usually reduced when temporal uncertainty about stimulus occurrence is minimized. Contrary to the common assumption attributing this RT benefit to speeding of motor processes, recent evidence suggests that temporal uncertainty might rather influence pre-motoric processing levels. We employed a backward masking procedure to further confine the locus of the temporal uncertainty effect. Participants had to discriminate whether a spatial gap within a Landolt square was either on the right or on the left side. In addition to shorter RT, visual discrimination performance was improved when temporal uncertainty was low. This result demonstrates that temporal uncertainty influences stimulus processing at a perceptual level.

Modulation of Cortical Feedforward Dynamics by Endogenous and Exogenous AttentionThomas Schmidt¹ and Anna Seydell²¹Universität Gießen, ²Universität Göttingen

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Single-cell recordings indicate that a visual stimulus elicits a wave of rapid neuronal activation that propagates so fast that it might be free of intracortical feedback. We traced the time-course of early feedforward activation by measuring pointing responses to color targets preceded by color stimuli priming either the same or opposite response as the targets. Effects of visual attention at the prime/target locations were studied by giving either an endogenous or an exogenous attentional cue, varying both the cue-prime and the prime-target SOA (stimulus onset asynchrony). Early pointing kinematics were time-locked to prime onset and independent of target onset, indicating that initial responses were controlled exclusively by the feedforward information elicited by the primes. However, early pointing dynamics were clearly modulated by attention at optimal cue-prime SOAs. Results indicate that visual attention modulates cortical feedforward dynamics in advance of critical stimuli.

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Systemsemiotic Predictive of Visual Recognition

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One important aspect of aesthetic research is the problem how to deal with meaning. The tradition of information aesthetics failed due to focussing only syntactic dimensions. We think, attractivity can not be understood without understanding attractors. At this point the empirical and the speculative perspective of research are touching each other. Understanding an effect means to be able to produce the effect. This is what we did: Reproducing the results of an empirical study using a systemsemiotic model of attractors.

Our expert system is an approach to deal with semiotic attractors using a rather simple visual interface. The aim was to reproduce the recall values of advertising elements in the studies of Czaiza (1998) and Stern (2001). Therefore we developed a model that contains the assumed most relevant factors as they appear in the literature. In order to keep the model as simple as possible, we tried to reduce the number of factors (as far as possible). The tested model was inspired by semiotics, and so the factors are of three groups: Syntactic, semantic and pragmatic factors. Each factor is implemented as an extra layer over the stimulus. In each layer the areas are manually marked by an operator, where the aspect is true. This was done as a binary differentiation (true, false). All the layers sum up to the values of the predicted recognition, at which every single layer has a different opacity (coefficient of relevance). The four syntactic factors are Size, Colour, Convexity and an additional layer for the Focus Periphery. The semantic factors are represented by four layers, which denote the Biological Codes, Cultural Codes, Scriptural Codes and the Individual Codes (which are Sub-Cultural Codes). The pragmatic factors are four again, which correspond with the Schema Affiliation, the Transactional Style (Rhetoric), the factor of Broken Taboos, and fourthly the signs for, who is the Sender/Origin of the message.

The model was applied to a set of 23 advertisements (with 145 elements), which were tested concerning the recognition values of the single graphic elements in advertising. And these recognition values were reproduced by our model even better than we expected (due to the simplicity of the model): We achieved a correlation of 0.946 between the empirically obtained values (Czaiza [1998] and Stern [2001]) and the predicted values from our model.

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Response Priming with Illusory Contour Figures

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Over the last decades there has been debate about whether the perception of illusory contour figures (ICs) is due to a purely stimulus-driven, feedforward process, or to a cognitive solution, including intracortical feedback processing. Here we use a response priming paradigm to address this question, because recent investigations [1] suggest that response priming reflects feedforward processing exclusively [2]. We report three experiments using ICs induced by “pacman” stimuli or line ends. Participants had to indicate whether the target shape was a square or diamond by making a speeded keypress choice response. IC primes were presented immediately before the targets at stimulus onset asynchronies (SOAs) varying from 35 to 106 ms; they were either the same shape as the target (congruent) or of opposite shape (incongruent). Even though participants could hardly identify the primes, clear response priming effects were observed such that consistent primes speeded responses to the target while inconsistent primes slowed them, with the size of the priming effect increasing with SOA [3]. We conclude that the ICs used here are able to rapidly trigger associated motor responses, consistent with the assumption that they arise from fast feedforward processing.

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Do Reversed Effects in Masked Priming Reflect Disguised Facilitation Rather than Inhibition?

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In masked visual priming, responding to a target is affected by prime-target congruency. In general, faster and more correct responses are observed after congruent primes (i.e. mapped to the same response as the target) as compared to incongruent primes. However, congruency effects may be reversed by inserting some delay between mask and target, such that congruent primes increase rather than reduce response times and error rate. Eimer and Schlaghecken [1], who discovered the Negative Congruency Effect (NCE), attribute it to self-inhibition of the primed response. Recently, this account has been questioned and the effect attributed to disguised facilitation of the prime-complementary response, due to pattern masks that contain the critical prime and target features. Analogous objections may be raised against NCEs observed with metacontrast masks [2]. The present experiments track the NCE time-course and show that the alleged perceptual prime-mask interactions do play a role. However, strong NCEs are found even for metacontrast masks that share no features with the non-presented prime. The NCE is not an experimental artifact, but reflects the action of inhibitory mechanisms.

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Auditory Perception

**The Perception of Relative Pitch of Octave-Complex Tones in a Dichotic Listening
Experiment: Central or Peripheral Mechanisms.**

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In our experiment subjects had to judge pairs of octave-complex tones with respect to their relative pitch as ascending or descending. Octave-complex tones, first devised by Shepard (1964), are composed of octave spaced sinusoids whose amplitudes are determined by a bell-shape spectral envelope. According to Shepards theory the relative pitch of a pair of octave-complex tones depends on the distance between individual partials [1]. The primary goal of our experiment was to test the theory proposed by Shepard. If the distance between individual partials is the key assumption for estimating relative pitch judgments, it should even hold for longer distances (more than one octave) or in dichotic listening conditions. The secondary goal of our experiment was to decide if there is one central or two independent pitch extraction mechanisms? Therefore the partials of each octave-complex tone were split into two sets, each presented to one ear. In this condition the change in distance of partials should lead to a change in perceived relative pitch. Our findings support this idea concluding that a central mechanism is involved in pitch extraction.

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Decision-Related Processes in Auditory Spatial and Pattern RecognitionTherese Lennert¹ and Werner Lutzenberger²

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Using magnetencephalography (MEG) we investigated non-invasively decision-related processes in humans employing an auditory spatial and pattern recognition task. Subjects were presented with two acoustic stimuli (S1, S2) which either differed in their spectral compositions (pattern) or in their localization in space (direction). Subjects had to indicate by button press whether the two stimuli differed in their pattern or direction. Statistical probability mapping revealed enhanced gamma-band activity (GBA) at 75Hz over parietal and at 64Hz over frontal areas for differences in direction and pattern, respectively. These results are in line with previous findings and support the assumption of a spatially separate dorsal and ventral auditory pathway. The amplitude of GBA over both areas was increased for easy compared to difficult trials. Early beta-band activity (BBA) which is related to response preparation was found bilaterally, suggesting that subjects prepare to press both buttons. Later in the trial, activity shifts to one hemisphere giving rise to the actual response. BBA at 38Hz was found over frontal areas peaking at 290ms after S2 onset. Activity was increased for difficult compared to easy trials, indicating the need for enhanced frontal processing in difficult decisions. BBA at 30Hz occurred over central areas peaking at 380ms after S2 onset; the amplitude did not differ between conditions. However, activation related to difficult trials was ~60ms delayed—in line with behavioural data: mean reaction time for easy trials was 68ms less than for difficult trials. These findings support the relevance of GBA for perceptual processes and suggest a crucial role of BBA over frontal and central areas in decision making and response preparation.

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Performance of *Myotis Nattereri* Foraging near Vegetation

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Natterer's bats (*Myotis nattereri*) are specialized in foraging close to vegetation where they search for prey by echolocation. Thus they face the problem of separating prey echoes from those generated by foliage. The degree of difficulty of such a task is influenced by the distance between prey and background and by the vegetation type. Generally the leaves of deciduous trees produce stronger echoes than the needles of conifers. Therefore we predict that with decreasing distance between prey and background structure the bats should have more problems detecting prey close to a broad-leaved hedge than close to a conifer. To test this hypothesis we trained Natterer's bats in a flight room to catch tethered mealworms that were offered in specific distances (ranging from 40 cm to 2 cm) in front of an artificial hedge simulating either a deciduous or a coniferous tree. Under infrared illumination we recorded the flight and echolocation behavior of the bats while they were capturing the mealworms. Their flight paths were reconstructed in 3D and synchronized with the emitted echolocation calls. We wanted to investigate possible strategies in flight and echolocation behavior that the bats use to solve detection tasks of increasing difficulty. The degree of difficulty was indicated by the capture success (the percentage of catches relative to the total number of flights in which the bat approached the hedge). At both vegetation types the distance between prey and vegetation influenced the flight behavior. Capture success decreased with distance between prey and hedge whereas the number of turns the bats performed in front of the hedge preceding a capture increased at the same time. At large distances (>10 cm) between prey and background structure the vegetation type did not influence the foraging behavior of the bats. When prey was offered at lesser distances it was more difficult for the bats to detect their prey near the broad-leaved tree than close to the conifer.

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Auditory Redundancy Gain

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Auditory redundancy gains were assessed in three experiments using a simple reaction time task. In each trial an auditory stimulus was presented either to the left ear, to the right ear, or simultaneously to both ears. The physical difference between auditory stimuli presented to the two ears was systematically increased across experiments. No redundancy gains were observed when the stimuli were identical pure tones (Exp. 1) or pure tones of different frequencies (Exp. 2). A clear redundancy gain and evidence of coactivation was obtained, however, when one stimulus was a pure tone and the other was white noise (Exp. 3). The results extend previous findings of redundancy gains and coactivation with visual and bimodal stimuli to the auditory modality. Furthermore, at least within this modality, the results indicate that redundancy gains do not emerge when redundant stimuli are integrated into a single percept.

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Computer Vision and Robotics

The Wägele: A Mobile Platform for Acquisition of 3D Models of Indoor and Outdoor Environments

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Efficient and comfortable acquisition of large 3D scenes is an important topic for many current and future applications like cultural heritage, web applications and 3DTV and therefore it is a hot research topic. We have built a platform for collecting the data needed to build such models: The Wägele. It is equipped with three laser range scanners, a panoramic camera, 3D-attitude and heading reference system and GPS.

One of the laser scanners is mounted to record range values horizontally. This data is used to build a two dimensional map and to localize the mobile platform with respect to this map. Our techniques to tackle this problem are borrowed from robotics and in essence we have to solve the simultaneous localization and mapping (SLAM) problem. The other laser scanners are mounted perpendicularly; their data yields the geometric information for the 3D model in form of slices of the environment. Additionally, panoramic images are taken regularly.

After a recording session the collected data is assembled to create a consistent 3D model in an offline processing step. First a 2D map of the scene is built and all scans of the localization scanner are matched to this map. After this step the position and orientation of the Wägele is known at each time step. The panoramic camera has been calibrated, and as the relative positions of all sensors are known, geometry creation and texture mapping is easy with the known positions. The result of this whole process is an unstructured point cloud with color attributes per point. For outdoor scenes, we georeference these models so that they can be embedded in coarse resolution models built from aerial images and digital elevation models.

Besides 3D model-acquisition, the platform also serves as a multimodal data acquisition platform. Due to the fact that the platform is localized continuously it can provide ground truth data for computer vision and other signal processing algorithms like stereo or visual localization and tracking algorithms.

Omnidirectional Stereo Based 3D Model Acquisition on the Wägele Platform using Graph Cuts

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Future 3D Television critically relies on mechanisms for automatically acquiring high quality 3D content of both indoor and outdoor scenes. Hassle free 3D acquisition of real scenes is also essential to provide content for the visualization of factory and office environments, cultural heritage sites and for perceptual graphics research. Stereo vision is one major approach to 3D modeling relying solely on the visual modality.

We present an omnidirectional stereo vision approach based on graph cut techniques in conjunction with a mobile sensor platform (“The Wägele”) where it is employed. The platform comprises an 8 Mpixel omnidirectional camera in conjunction with a laser scanner, no odometry is necessary. 3D models are acquired just by moving the platform around and recording omnidirectional images in conjunction with their poses in regular intervals. The result of this whole process is a colored point cloud. The poses and thus the according external camera parameters are determined by probabilistic matching of laser scans. However, the stereo vision algorithm does not rely on this laser range data directly, any other method of localization would do. The stereo pipeline computes dense depth maps using pairs of panoramic images taken from different positions. First, for each pixel in the first image the epipolar curve in the second image is created and a difference value for each disparity on this epipolar curve is computed. Afterwards, a graph cut algorithm as the core component is applied. The graph cut approach has become quite attractive for various vision problems targeting high quality. Our algorithm follows the work of Kolmogorov & Zabih and is extended to omnidirectional imaging. The key of graph cut is formulating the correspondence problem as an energy minimization problem. The minimization is done iteratively by transforming this problem into several minimum cut problems based on alpha-expansion moves until convergence is reached. Our energy function comprises an SSD-based matching cost, an occlusion term and a smoothness term. Afterwards, several post processing steps are applied: sub-disparity refinement, epipoles removal, floor correction and filling of unknown values. Results of both indoor and outdoor scenes are presented. Besides targeting on an appealing visual quality (from a perceptual perspective) it is also important to objectively give a quantitative measure of the quality of our stereo method. This requires two components: acquiring ground truth and the design of a quality measure. Two additional calibrated laser range scanners on the Wägele deliver a well approximation of ground truth of the geometry. Texturing it leads also to point clouds that can be visually compared to our stereo results by the beholders. In terms of quantitative comparison, first results of our 3D based measure are presented.

An Affine Invariant Scene-Graph for Object Recognition and Navigation

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Spatial representations (cognitive map models) as used for autonomous systems usually contain information only relevant for navigation, i.e. information about the location of landmarks. In order to build a cognitive agent, which is able to fulfill tasks different from navigation (like e.g. object manipulation) it becomes necessary to enrich the spatial representation with the representation of objects which are not primarily relevant to navigation. Both, the problem of cognitive mapping and the problem of view invariant object recognition can be ascribed to the problem of finding corresponding features between widely separated views. Solutions to this problem can be based on affine invariant feature transforms, like e.g. the scale invariant feature transform (SIFT). Commonly, calculation of the feature transform is restricted to few salient locations (keypoints) which can be considered to be equivalent to the location of extrema of continuous saliency maps.

The keypoints are arranged as a graph structure containing information, both on navigation and object recognition. Our goal is to separate the scene graph into these two components. We present the algorithm used to derive the graph structure. It will be shown that the keypoint localization (i.e. location, orientation, and scale) as well as the neighborhood relation keeps stable under a wide variety of changes. This includes changes in illumination (uniform and non-uniform), shadows, partial occlusion and object deformation. The proposed algorithm can be run in real-time.

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A Model of Theory-Of-Mind Based on Action Prediction

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Theory-of-Mind, or mentalising, is defined as a cognitive process used to understand other people's actions based on mental states. Two main theories of mentalising have been put forward in recent years: Simulation Theory and Theory-Theory. We propose a model of mentalising based on action prediction and semantic representation. The model would be triggered whenever a human observer detects a potential agent (particularly other humans, but also other animals or active entities). On the basis of their actions, it would associate a possible mental state to the observed agent and predict its future behaviour. To do this, first a search engine would look for a potential mental state matching an observed action in a look-up table containing action-mental state associations acquired through experience. Then, a predictor would calculate a possible next action for the observed agent on the basis of the mental state, and a comparator would compare this predicted action to the actual next action of the agent. If the discrepancy between predicted and actual behaviour is greater than a threshold, the mental state is rejected and the process repeated until a conclusive match or abandon. The predictor is postulated to be similar to mechanisms thought to underlie motor learning or reinforcement learning, while the look-up table could resemble semantic representations of objects or faces.

The model could also be used for active interaction with other agents: the search engine would find an action to be executed by the observer in order to induce a particular mental state in the observed agent. Success could be assessed by the model through observation of the other agents' reaction.

The neural correlates for this model are likely to be distributed and could include the posterior part of the superior temporal sulcus, the medial prefrontal cortex, the temporal poles, the premotor cortex and the cerebellum. To assess the plausibility of the model and test possible associations between particular neural structures and the components of the model, we review previous studies of the neural correlates of mentalising and some associated processes.

Multimodal Interactions: Sensory Integration

Face Distinctiveness can be Modulated by Cross-Modal Interaction with Auditory StimuliIsabelle Bühlhoff¹ and Fiona N. Newell²¹MPI for Biological Cybernetics, Tübingen, ²Trinity College, Dublin

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In this study we ask whether visually typical faces can become perceptually distinctive when they are paired to auditory stimuli that are distinctive. In a first set of experiments (Bühlhoff & Newell, ECVP 2004), we had investigated the effect of voice distinctiveness on face recognition. Memory for a face can be influenced by the distinctiveness of an utterance to which it has been associated. Furthermore, recognition of a familiar face can be primed by a paired utterance. These findings suggest that there is a tight, cross-modal coupling between the faces presented and the associated utterances and that face distinctiveness can be influenced by cross-modal interaction with auditory stimuli like voices. In another set of experiment, we used instrumental sounds instead of voices and showed that arbitrary auditory stimuli could also affect memory for faces. Faces that had been paired with distinctive instrumental sounds were better recognized in an old/new task than faces paired to typical instrumental sounds. Here we investigated whether these instrumental sounds can also prime face recognition although these auditory stimuli are not associated to faces naturally as voices are. Our results suggest that this is not the case; arbitrary audio stimuli do not prime recognition of faces. This finding suggests that attentional differences may have resulted in better recognition performance for faces paired to distinctive sounds in the old/new task. It also suggests that utterances are easier to associate closely to faces than arbitrary sounds. In a last set of experiments we investigated whether the voice priming effect shown in the first set of experiments might be based on the use of different first names in each utterance. Thus, we asked whether semantic rather than perceptual information was determinant in the used utterances. We repeated the priming experiment using the same voice stimuli, but name information was removed. The results show that there is still a significant priming effect of voices to faces, albeit weaker than in the full voice experiment. The semantic information related to the first name helps but is not be decisive for the priming effect of voices on face recognition.

Why Two “Distracters” are Better than One: Modelling the Effect of Non-Target Auditory and Tactile Stimuli on Visual Saccadic Reaction Time

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In a cross-modal focussed-attention (FA) task, stimuli from one modality are designated as targets, whereas stimuli from one or more other modalities are defined as non-targets (“distracters”) that subjects are instructed to ignore. Saccadic reaction time (SRT) was measured in a FA task with visual target stimuli (LED) and auditory (white noise burst) and tactile (vibration applied to palm) stimuli as non-targets. Depending on the spatial and temporal configuration of the stimuli, mean SRT in cross-modal conditions was facilitated by up to 30 ms compared to unimodal (visual) stimulation. Second, mean SRT monotonically increased the later non-targets are presented. Third, mean SRT decreased with the number of non-targets present. Fourth, mean SRTs were shorter when target and non-targets were both presented in the same hemifield (ipsilateral) rather than in opposite hemifields (contralateral).

These results are considered within the framework of the time-window-of-integration (TWIN) model proposed in [1] and [2]. TWIN distinguishes an early, afferent stage of peripheral processing followed by a compound stage of converging subprocesses. The first stage consists in a race among the peripheral neural excitations in the sensory pathways triggered by a cross-modal stimulus complex assuming statistically independent sensory channel processing times. The second stage comprises neural integration of the input and preparation of an oculomotor response. Cross-modal interaction manifests itself in an increase or decrease of second stage processing time. However, it occurs only if a non-target stimulus wins the race in the first stage opening a “time window” such that the termination of the target peripheral process falls within the window.

Without making specific distributional assumptions, it can be shown that the expected amount of cross-modal interaction in TWIN (defined as mean SRT in unimodal trials minus mean SRT in cross-modal trials) is the product of the probability of interaction to occur and the amount of interaction (in ms). The first factor is modulated by stimulus onset asynchrony (SOA) and by unimodal stimulus properties such as intensity. Cross-modal stimulus properties, such as spatial disparity between target and non-targets, may affect the amount of cross-modal interaction in the second stage. Having two (or more) non-targets of different modalities partaking in the race should increase the probability of one of them winning it, thus increasing the probability of cross-modal interaction.

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[2] Diederich, A. and Colonius, H. (2004). In G. Calvert, C. Spence, and B. E. Stein (Eds.), *Handbook of multisensory processes* (pp. 395–408). Cambridge, MA: MIT Press

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Exploring Connections Between Similarity and Categorization using Vision and Touch

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Similarity has been proposed as a fundamental principle underlying the formation of category structures. Much of the research involving perceptual similarity and categorization, however, has focused on a single modality, usually vision. Can the notion of similarity still provide a basis for explaining categorization when objects are perceived with one or more modalities? We addressed this question by having subjects see, touch, or both see and touch novel, 3D objects which varied parametrically in shape and texture. Subjects performed a pair-wise similarity rating task followed by a free sorting categorization task. Using multidimensional scaling (MDS), we found that a single underlying perceptual map whose dimensions corresponded to shape and texture could explain visual, haptic, and bimodal similarity ratings. However, the relative weights of the map's dimensions varied according to modality: shape dominated texture when objects were seen, whereas shape and texture were equally important in the haptic and bimodal conditions. We found some evidence for a connection between similarity and categorization in a multimodal context: the probability of category membership increased with similarity, while the probability of a category boundary being placed between two stimuli decreased with similarity. Moreover, the relative weight accorded to shape and texture varied in the same way for both tasks when modality was changed.

Separating Multisensory Integration from Unspecific Warning Effects in Saccadic Reaction Time

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Saccadic reaction time (SRT) to visual targets tends to be faster when auditory or tactile stimuli occur in close temporal or spatial proximity even when subjects are instructed to ignore the auditory or tactile non-target (focussed-attention (FA) paradigm). Since for this paradigm the non-target often appears before the target, it may act as an alerting or warning cue rather than an enhancing stimulus for crossmodal integration to occur.

Saccadic reaction time (SRT) was measured in a FA task with visual target stimuli (LED) and auditory (white noise burst) and tactile (vibration applied to palm) stimuli as non-targets. Non-targets were presented ipsi- or contralateral to the target with 23 different stimulus-onset-asynchronies (SOA) over a range of 700 ms. Depending on the spatial and temporal configuration of the stimuli, mean SRT in cross-modal conditions was facilitated by up to 45 ms compared to unimodal (visual) stimulation. Second, when the non-target was presented between 500 and 150 ms prior to the target, mean SRT reduction was nearly the same over this range, regardless of the laterality of the non-target. Third, when the non-target was presented between 150 and 0 ms prior to the target mean SRT first decreased and then increased the later non-targets were presented. Mean SRTs were shorter when target and non-targets were both presented in the same hemifield (ipsilateral) rather than in opposite hemifields (contralateral).

These results are considered within the framework of the time-window-of-integration (TWIN) model proposed in [1] and [2]. TWIN distinguishes an early, afferent stage of peripheral processing followed by a compound stage of converging subprocesses. The first stage consists in a race among the peripheral neural excitations in the sensory pathways triggered by a cross-modal stimulus complex assuming statistically independent sensory channel processing times. The second stage comprises neural integration of the input and preparation of an oculomotor response. Cross-modal interaction manifests itself in an increase or decrease of second stage processing time. However, it occurs only if a non-target stimulus wins the race in the first stage opening a “time window” such that the termination of the target peripheral process falls within the window. TWIN is extended here to allow separation of a—spatially unspecific—warning effect from true multisensory integration.

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[2] Diederich, A. and Colonius, H. (2004). In G. Calvert, C. Spence, and B. E. Stein (Eds.), *Handbook of multisensory processes* (pp. 395–408). Cambridge, MA: MIT Press

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Visuo-Haptic Binding in Young Adults and 5-Year-Old Children

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When participants grasp an object while simultaneously watching it through an anamorphic lens, their haptic estimates of object size—as measured by comparisons with other objects grasped without vision—are strongly biased towards the discrepant visual information. In this setup haptic and discrepant visual signals are derived from the same spatial location and the two signals recognizably derive from the same object. Under these conditions, haptic bias towards vision has been observed for adults as well as children—the younger the children, the more pronounced is the effect [1]. Here, we investigated for 5-year-old children and young adults (20–25 years of age) whether spatial superimposition of haptic with discrepant visual signals from a second object suffices to bias haptic estimates towards vision and whether age-dependent shifts in the reliabilities of the single modalities can explain age differences in bias [cf. 2]. Participants in our experiment compared the length of two bars in one of three conditions: using haptics only, using vision only or using haptics-plus-vision. In the haptics-plus-vision condition, one of the two felt bars was spatially superimposed by discrepant visual information presented via a mirror. Using the method of constant stimuli, we measured discrimination thresholds in all three conditions and the point of subjective equality of the visuo-haptic to haptic stimuli in the haptics-plus-vision condition. Discrimination thresholds were three times larger for haptic-only as compared to vision-only conditions, but we did not find any age differences in these conditions. This finding is not consistent with the idea that age differences in reliabilities are responsible for age differences in the amount of haptic bias towards vision. However, in the haptics-plus-vision condition, discrimination thresholds in adults were as low as vision-only thresholds, whereas in children they were similar to haptic-only thresholds. Moreover, in the adult group we observed haptic bias towards vision, but not in the children. These results suggest that spatially superimposed discrepant visual information is automatically bound with haptic information in adults, but not in 5-year old children. Taken together, our findings show no quantitative age differences in the reliabilities of the single modalities per se, but point to qualitative differences in the binding of visual and haptic information.

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Visual Influence on Tactile Localization

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The primary source of information to determine where on the body we are being touched is derived from the somatosensory system. However, can visual information influence the perceived location of touch on the body? Ten participants localized a brief air puff (about 250 ms) applied to the smooth ventral surface of the right forearm somewhere between wrist and elbow. Localization was measured with a 2AFC paradigm in which participants judged the location of the tactile stimulus relative to a visual reference using two opposing 1-up/2-down staircases. Participants' task was to indicate whether the air puff was closer or further from the wrist relative to the reference. In one condition the visual reference was a line drawn on the forearm midway between elbow and wrist (AIR ONLY). In another, the air puff was accompanied by a temporally synchronous line of laser light projected onto the reference location (AIR+LASER). The experiment was analogous to that of Bertelson and Aschersleben [1], which investigated visual influences on auditory localization. Based on this, we expected the synchronous light to facilitate multimodal integration and therefore affect tactile discrimination performance without introducing a bias. In the AIR ONLY condition the PSE was on average on the reference location. Surprisingly, in the AIR+LASER condition we did not find a change in discriminability relative to the AIR ONLY condition. We found, however, a significant shift of the PSE by 0.9 cm towards the elbow. This bias was evident in eight out of the ten participants. This demonstration of a visual effect on tactile localization may indicate that judging the location of a visual reference on the body is not free from biases.

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Integration of Shape Information from Vision and Touch: Optimal Perception and Neural Correlates

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Recently, Ernst and Banks (2002) showed that visual-haptic size information is integrated in a statistically optimal manner, i.e. visual and haptic size estimates are weighted according to their reliabilities. Here we investigate whether the same is true for visual-haptic shape information. We further explored the neural substrates underlying visual-haptic integration in shape processing using fMRI and examined whether neural activity elicited by multisensory integration correlates with cue weighting.

For this we used ridges of elliptical objects that subjects could see and/or feel. Subjects saw the front of the object and they felt the back. The elongation of the elliptical ridges on both sides of the objects could differ and subjects' task was to decide whether the ellipse was elongated vertically or horizontally. This way we could study the weight of vision and touch during shape discrimination. We varied the weight given to vision by degrading the visual information, using blur.

The psychophysical experiments showed that visual and haptic shape information is integrated in a statistical optimal way even when the visual information is displayed via a mirror. That is, we observed a decrease in visual weight when vision was degraded and thus less reliable. Furthermore, we found an increase in discrimination performance when both modalities were presented together. These results were crucial since the fMRI experiments relied on presenting objects in a mirror.

We also determined neural activity with fMRI while individuals were performing the same ellipse discrimination task. When the visual reliability is reduced in the visual-haptic task, neural responses decreased in the lateral occipital cortex while increased in the anterior intraparietal cortex, a brain region strongly involved in multisensory integration.

[1] Ernst, M.O. and Banks, M.S.: Humans Integrate Visual and Haptic Information in a Statistically Optimal Fashion. *Nature* 415, 429–433

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Haptic Exploration Behavior During Bimodal Object Recognition

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For the purpose of object recognition, the combination of complementary information derived from the different sensory systems (vision and touch) should result in a rich representation of the object in memory and may consequently enhance recognition performance.

The purpose of this study is to investigate the haptic exploration behavior during bimodal object recognition. Specifically, we asked whether the exploration behavior for recognition depends on what modality was used during learning of an object.

Analog to [1], we designed an old/new object recognition task using novel objects built each from 6 Lego bricks. In each condition subjects had to learn 4 novel object shapes either haptically (H), visually (V), or combined haptically and visually (VH). In a following recognition phase we added 4 distractor objects and subjects had to decide whether the presented object was known (old) or unknown (new) from the learning phase. The recognition phase was always bimodal (VH).

We tested 12 subjects in all three conditions (V-to-VH, H-to-VH, VH-to-VH) measuring recognition performance. Subjects exploration behavior was recorded using video tape. For technical reasons, the recordings of only 8 subjects was used for the video analysis. Therefore, the video was cut into single clips each showing the exploration of one stimulus. These clips were replayed in randomized order to raters, who judged the ‘hapticallity’ of subjects’ exploration behavior on a scale with 9 possible answers between ‘subject just held and turned the stimulus’ to ‘subject explored the stimulus with fingers’. We found ‘hapticallity’ during visual-haptic recognition was judged largest for the exploration following haptic learning (H-to-VH), smallest for the one following visual learning (V-to-VH), and intermediate for visuo-haptic learning (VH-to-VH).

This suggests that subjects use a strategy when recognizing the objects in a way that they match the exploration behavior between learning and recognition test. They use the haptic modality for recognition when the object was learned haptically. When the object was learned visually they predominantly use the visual modality during recognition ignoring touch. Also when the object was learned bimodally (VH), the exploration strategy was matched between learning and recognition test here indicating that the haptic modality was used almost exclusively for actively manipulating the object but not for exploring its shape.

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Reinforcement Learning of Automatic Integration of Navigation Strategies Based on an Infomax Principle

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The ability to return to a known place has drawn interest in modeling the navigation behaviour of both animal and robotic systems capable of exploring unknown environments. In particular, we are interested in the integration of three local navigation mechanisms: obstacle avoidance, scene based homing, and path integration. In order to decide which mechanism to pursue in each specific situation, a robot needs to know which of the incoming sensory information is reliable and which information needs to be confirmed by further measurement. Therefore, the decision policy should allow the generation of intermediate behaviors subject to the confidence values of each mechanism. This is problematic in hardwired frameworks such as the subsumption architecture. In contrast, reinforcement learning can be used to generate flexible decision policies of the required type.

Reinforcement learning is based on the estimation of the reward, which can be expected from an action carried out in a certain situation (state). As an important step towards a reinforcement-based integration scheme, we present an algorithm for estimating the reward function Q and for optimally exploring its values in state space. Since the state space and the action space are continuous, we approximate the reward function by a generalized radial basis function (GRBF) expansion. The learning algorithm is derived in a probabilistic framework. In order to create an efficient algorithm we apply a relaxation method which makes use of the locality of the radial base system. The learning process is accelerated by choosing actions (i.e., sampling points of the Q -function) which maximize information gain for each learning step. The behaviour of the algorithm has been tested numerically for the problem of noisy function interpolation.

Multimodal Interactions: Sensory-Motor Integration

Initiation of Smooth-Pursuit Eye Movements by Real and Illusionary Contours

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The initiation of smooth-pursuit eye movements (SPEM) has been used already as a tool to describe properties of the human pursuit system. In an attempt to describe low-level motion processing mathematically, elementary motion detectors (EMDs) of the correlation type play an important role to generate raw motion signals. As in everyday life, EMDs perceive movement of an extended boundary only perpendicular to its own orientation, due to a limited range of view. Since neurons in V1 have small receptive fields, they are strongly influenced by this “aperture problem”. Given that unambiguous elements, such as line-endings, are available, neurons in macaque Area MT provide the solution to the “aperture problem” evidently after ~ 60 ms, but their erroneous initial responses apparently influence the oculomotor response (Born&Pack 2001)[1]. In accordance with cybernetic models employing EMDs, presaccadic SPEM start with an initial direction error, which is compensated ~ 300 ms after target onset (Masson&Stone 2002)[2]. Firstly we tried to replicate these findings in our setup and secondly asked whether these directional errors can also be observed if illusionary contours are tracked. Horizontal and vertical eye positions of five subjects were recorded at 1kHz using infrared oculography (IRIS Skalar). Two synchronised computers performed the task of presenting stimuli and measuring data simultaneously. Stimuli were presented at a viewing distance of 57cm on a 19” CRT-Screen (width:36.2°, height:27°), at a resolution of 1600x1200 pixels and a refresh rate of 104.5Hz. The real contour, a white bar on black background, length:20°, width:0.5°, induced an significant initial direction error ($22.85^\circ \pm 5.72^\circ$) when tilted 45° with respect to moving direction, as described earlier. Moreover the tilted bars yielded significantly longer saccadic latencies than the untilted bars ($197.3\text{ms} \pm 23.8\text{ms} > 177.6\text{ms} \pm 22.9\text{ms}$, $P < 0.05$). Three different kinds of illusionary contours preserving size of the real contour were tested: i) only the endpoints of the real contour, ii) different portions of the real bar occluded by a white bar centered on the screen and parallel to moving direction, iii) interleaved line-endings of two gratings (spatial frequency: 2 or 4 cyc/°) defining the illusionary contour. These illusionary contours lead to significantly longer saccadic latencies compared to the real contours ($234.0\text{ms} \pm 37.5\text{ms} > 190.8\text{ms} \pm 25.0\text{ms}$, $P < 0.001$). Regarding the initial direction error, illusionary contours turned out not to have an effect as robust as real contours. The direction error seems to be more related to the amount of peripheral stimulation than to the Gestalt perception of the individual illusionary contour.

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Frontal Field Activity Represents Anticipatory Eye Movements and Behavioral Task Segmentation

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Since smooth pursuit eye movements (SPEM) can not be executed voluntarily, these eye movements can be used to quantify the ability to predict or anticipate future events. Our paradigm consists of ramp-like target trajectories with constant speed (5, 10 or 15 °/s, respectively) and constant direction. In 50% of the trials, the moving target was initially invisible for 500 ms. As a control, we used ramps randomized to the left and right with 5, 10 and 15 °/s, respectively. The eye movements were recorded via the search coil system and the visual stimuli were presented via a video projector (1024 x 768 pixel at 123 Hz) onto a tangent screen (70 x 64 deg). We calculated the mean smooth eye velocity in the time window 100 ms before the appearance of the moving target. Trials with saccades in that time interval were excluded from further analysis. We performed an ANOVA to determine the influence of the expected target velocity on the smooth eye velocity. The monkey indeed performed anticipatory SPEM in the expectance of a moving target (ANOVA $p=0.013$) similar as our human subjects. We recorded single-unit activity from the frontal eye field (FEF) using a five channel MiniMatrix. So far, we are able to categorize the observed single-unit responses into two classes. First, 22 neurons whose activity showed clear pursuit-related response properties, displayed an obvious increase in activity during the 500 ms period while the monkey anticipated the appearance of the target. Second, 32 neurons responded with a peak in activity representing segments in the oculomotor task such as the transition from fixation to pursuit or from fixation to saccade, respectively. Occasionally, these peaks start prior to the triggering events. They are not selective for the type of eye movement. Taken together, our results suggest that the activity in the FEF is not only influenced by sensory (bottom-up) events, but also by internal, top-down signals guiding motor programs.

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The Use of Visual Memory for Grasping

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We tested which components of visual memory are most important for grasping by varying the amount of visual feedback available to the participants during a grasping movement. Furthermore we examined the effects of visual memory on grasping kinematics. 48 participants had to grasp bars of different lengths (39 mm, 41 mm, 43 mm) but constant width (8 mm) and depth (5 mm) after a preview period of 1 s and in response to an auditory cue. There were four different visual conditions, which were designed to increase memory load successively: (1) full vision of hand and target during grasping, (2) full vision until movement initiation, (3) full vision until start signal, (4) no vision and 5s-delay (visual occlusion for a period of 5 s before the start signal was given and movement initiation started). Note that the main difference between the conditions (2) and (3) was the target visibility during the reaction time interval. For each movement the grip aperture between index finger and thumb was analyzed as a function of time. In accordance with earlier studies [1, 2, 3], we found that maximum grip aperture was consistently larger for the longer targets ($F(1.7, 78.3) = 68.7, p < .001$) and increased with higher memory load ($F(2.1, 96.5) = 168.5, p < .001$). The most prominent increase in grip aperture was found between condition (1) and (2). In addition, the increase in grip aperture between condition (2) and (3) was equally large as the increase of grip aperture between condition (3) and (4), although in the first case the hold time in memory was increased by only 350 ms whereas in the second case it was increased by 5 s. This suggests either an exponential decrease of the memory trace or that the critical programming of the movement takes place during the time period between go-signal and movement beginning.

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Eye Movements in Reading—Scrolling Text Compared to Static Text.

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In order to gain further insights into eye movement control during reading, we tried to reveal whether reading eye movements differ or are similar when subjects read scrolling or static text. Text presentation as well as data acquisition were done using two synchronized computers. Three examples of text were presented on a single line on an 19" CRT display in white on black. Either the text scrolled ($23^\circ/s$) from left to right, or a single line was displayed until the subject pressed a key and the next line was presented. The eye movements of 19 subjects were measured by infrared oculography (Iris Skalar). Each reading session lasted for 60 s. Three texts were used, varying in difficulty due to being built of words ranging from long (mean word length 7.1 letters) and rare to short (mean 5 letters) and extremely common, i.e. taken from the 400 most common German words. Saccades were automatically detected based on an acceleration threshold criterion from the horizontal eye position profiles. Eye movements while reading horizontally scrolling text were found to be more uniform compared to reading static text. Mean fixation time obtained by the scrolling text was 188 ms (+ 84 ms, $n=15054$), whereas static text resulted in 192 ms (+ 110 ms, $n=15537$). Mean saccade amplitude was 3.4 deg (+ 5.9 deg, $n=15105$) for scrolling text compared to 0.7 deg (+ 10 deg, $n=15561$) for static text. Additionally, for scrolling text the number of regressive saccades, i.e. saccades to a location that was passed by, dropped from 43 (+6) to almost none 7 (+3). The given values relate to our complete set of data consisting of 19 subjects reading three different texts per presentation method each. At the same time, while subjective ease of reading is diminished, text comprehension as measured by questions regarding content remains on the same level as for static text. Both factors point to an increased quota of automation in eye-movement control independent of word identification.

The Psychological Refractory Period: Is Response Execution Part of the Central Processing Bottleneck?

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The standard bottleneck model of the psychological refractory period (PRP) assumes that the selection of the second response is postponed until the selection of the first response has been finished. Accordingly, dual-task interference is attributed to a single central processing bottleneck involving decision and response selection but not the execution of the response itself. In order to critically examine the assumption that response execution is no part of this bottleneck, we systematically manipulated the temporal demand for executing the first response in a classical PRP paradigm. Contrary to the assumption of the standard bottleneck model, this manipulation affected the reaction time for task 2. Specifically, reaction time of task 2 increased with the execution time of task 1. This carry-over effect from task 1 to 2 provides strong evidence for the notion that response execution is part of the processing bottleneck, at least, when task 1 involves a continuous movement.

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Active Arm Movement Impairs Tactile Discrimination Performance

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It is well known, that sensory consequences of self-produced movements can be predicted and that this prediction can be used to attenuate the sensory effects. It has been shown that the cerebellum is involved in predicting the sensory feedback of self produced movements and thus it can modulate the somatosensory cortex activity [1].

In this study it is planned to investigate the performance of a tactile discrimination task during rest and compare it to performance during active arm movement, respectively. Participants' distal phalanx of the left index finger was glued to a metal pin of a custom developed Lateral-Pin-Stroke-Device (LPSD) in order to provide pure skin stretch and to avoid cues derived from pin slip parallel to the skin. The device is able to move the pin on a defined trajectory in any radial lateral direction initiating from a central starting point. The task was to judge whether the second of two pin strokes was shifted clockwise or counterclockwise compared to the first. This experiment was performed under two different conditions—a static condition where no arm movement was required and an active condition where participants had to perform an arm movement in forward direction while they were doing the discrimination task.

Preliminary results show that direction discrimination performance is much higher in the static condition. Participants were no longer able to reach the 84% discrimination threshold in the active condition. These results are consistent with our expectations, i.e., a significantly impaired tactile sensation during active movement. In analogy to saccadic suppression we will discuss our results in terms of tactile suppression. Results indicate a slight anisotropy in terms of a higher threshold in upwards- (towards the finger tip) compared to rightwards direction. This seems to be in line with Keyson and Houtsma's [2] findings.

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On the Time Course of a Specific Interference Effect of Action on Perception

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Action-effect blindness refers to the finding that planning an action hinders the perception of a compatible stimulus (e.g., planning a right button press renders the identification of a right-pointing arrow more difficult than that of a left-pointing arrow [1]). A related specific interference effect was found in the continuous paradigm of Schubö, Aschersleben and Prinz [2,3], in which participants were asked to produce hand trajectories of varying amplitudes while watching motions of a dot on a screen. Their results showed that a medium-amplitude dot motion was perceived as larger when participants simultaneously performed a small-amplitude movement than when they performed a large-amplitude movement. This over/underestimation of perceived motion amplitudes was defined as a contrast effect (CE). A similar effect was found in a paradigm by Hamilton, Wolpert, and Frith [4], where people had to judge the weight of objects that were lifted by actors in a movie while concurrently lifting objects of varying weights. They also found a CE, in that lifting a heavy weight resulted in lower perceived weights than when lifting a light weight. The effect of action on perception was measured rather indirectly through subsequent motor production in the studies by Schubö and colleagues, and with a rating scale in the case of Hamilton and colleagues. In the present study, a more explicit perceptual measure was employed and the time course of the effect of action on perception was investigated. To do so, participants were asked to produce hand movements in a given direction while watching a static line that pointed in a dis/similar direction. To assess the perceived line direction, participants were subsequently required to stop a rotating line when they felt it matched the direction of the previously seen static line. To establish the time course of potential effects, the static line was only briefly presented (~14 ms) at 0, 300, or 1000 ms after movement onset. Consistent with the CEs reported above, perceived directions were repulsed by the direction of the hand movements. Moreover, the size of the CEs remained constant across the different presentation times. A model that can account for the CE and its time course will be discussed.

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Natural Image Statistics

Factorial Coding of Natural Images: How Effective are Linear Models in Removing Higher-Order Dependencies?

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The performance of unsupervised learning models for natural images is evaluated quantitatively by means of information theory. We estimate the gain in statistical independence (the multi-information reduction) achieved with independent component analysis (ICA), principal component analysis (PCA), zero-phase whitening, and predictive coding. Predictive coding is translated into the transform coding framework, where it can be characterized by the constraint of a triangular filter matrix. A randomly sampled whitening basis and the Haar wavelet are included into the comparison as well. The comparison of all these methods is carried out for different patch sizes, ranging from 2x2 to 16x16 pixels. In spite of large differences in the shape of the basis functions, we find only small differences in the multi-information between all decorrelation transforms (5% or less) for all patch sizes. Among the second-order methods, PCA is optimal for small patch sizes and predictive coding performs best for large patch sizes. The extra gain achieved with ICA is always less than 2%. In conclusion, the ‘edge filters’ found with ICA lead only to a surprisingly small improvement in terms of its actual objective.

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Visibility of Temporal Blur in Natural and in Synthetic Scenes

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We investigate the visibility of temporal blur as a function of retinal eccentricity. We use a novel gaze-contingent display that allows us to vary the spatio-temporal characteristics of image sequences under natural viewing conditions [1]. This gaze-contingent display uses a temporal multiresolution pyramid that is computed in real time. Different pyramid levels are then interpolated as a function of gaze to simulate an arbitrary resolution map. Using this system, we have shown previously that in natural scenes, a selective filtering of higher temporal frequencies in a ring-shaped region around the center of gaze remains unnoticed over a wide range of frequencies [2]. The level to which temporal blur can be introduced increases dramatically with eccentricity. In the set of experiments presented here, we compare these findings with the visibility of temporal blur in dynamic noise with varying spectral characteristics. We tested white noise (uniform spectral content) as well as pink noise ($1/f$ spectral falloff) that was temporally lowpass-filtered to model the temporal correlation across consecutive frames that is a property of natural scenes. 3 subjects watched 20s long video clips (1024x576 pixels spatial, 30 frames per second temporal resolution) where higher temporal frequencies were filtered only in a ring-shaped region of width 2.5 degrees at an eccentricity of 0, 10, 20, or 30 degrees. After stimulus presentation, subjects had to indicate whether they had perceived any temporal blur. Threshold frequencies were then adjusted in an interleaved staircase procedure. Results show that there is a qualitative difference between natural and synthetic sequences. Contrary to the effect found in natural scenes, detection thresholds for temporal blur do not vary significantly with eccentricity both in white and pink noise sequences. In white noise, temporal blur can be detected more easily (detection threshold at about 25Hz) than in pink noise (18Hz). We will discuss several hypotheses about the cause of this perceptual difference between natural and synthetic dynamic scenes.

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Classification of Natural Scenes: Critical Features Revisited

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Human observers are capable of detecting animals within novel natural scenes with remarkable speed and accuracy. Despite the seeming complexity of such decisions it has been hypothesized that a simple global image feature, the relative abundance of high spatial frequencies at certain orientations, could underly such fast image classification [1].

We successfully used linear discriminant analysis to classify a set of 11.000 images into “animal” and “non-animal” images based on their individual amplitude spectra only [2]. We proceeded to sort the images based on the performance of our classifier, retaining only the best and worst classified 400 images (“best animals”, “best distractors” and “worst animals”, “worst distractors”).

We used a Go/No-go paradigm to evaluate human performance on this subset of our images. Both reaction time and proportion of correctly classified images showed a significant effect of classification difficulty. Images more easily classified by our algorithm were also classified faster and better by humans, as predicted by the Torralba & Oliva hypothesis.

We then equated the amplitude spectra of the 400 images, which, by design, reduced algorithmic performance to chance whereas human performance was only slightly reduced [3]. Most importantly, the same images as before were still classified better and faster, suggesting that even in the original condition features other than specifics of the amplitude spectrum made particular images easy to classify, clearly at odds with the Torralba & Oliva hypothesis.

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Manifesto for the Study of Material Perception

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When we look at everyday things, we not only perceive their 3D shape and identity, but also we generally enjoy a distinct visual impression of their material properties. Without touching an object, we can usually tell at a glance whether it is soggy or dry, soft or hard, smooth or rough. How does the visual system recognize materials? What are the major challenges that the visual system faces? Despite the enormous variety and vividness of material perception, it is only just beginning to emerge as a major topic of study in vision research [e.g. 1–7]. Here I present a framework for understanding human visual perception of materials and introduce a number of novel demonstrations of our visual aptitude for estimating material properties.

The main thesis I will present is that despite our exquisite sensitivity to changes in physical states (e.g. subtle changes in appearance allow us to tell the difference between fresh and stale bread) the visual system does not generally estimate the intrinsic physical attributes of materials (e.g. density or coefficient of viscosity). Instead, it adopts a heuristic strategy for classifying material appearance based on the statistical behaviour of materials in our environment. In the real world, the observed appearance of a material is subject to constraints such as gravity and natural illumination conditions. Consequently, there exists a large set of simple low-level image measurements (e.g. contrast distributions, amplitude spectra, optic flow patterns, etc.) that reliably correlate with changes in physical state.

I will present a taxonomy that organizes these cues, and embed all extant research on material perception within this framework. Broadly I organize the cues into three classes: (1) optical cues, i.e., information arising from the manner in which a material interacts with light, such as its specular reflectance, or sub-surface scattering coefficients. This class of cues has received the most attention, as there is a considerable body of work on the estimation of diffuse albedo and colour. (2) geometric cues, i.e., the characteristic 3D shapes adopted by a material subject to natural forces. (3) dynamic cues, i.e., the way that a material tends to change shape over time or interact with other objects in the scene. I use a variety of physics-based computer graphics simulations to demonstrate these cues and their low-level correlates. Finally I show circumstances under which high-level (cognitive) factors can influence our perception of materials.

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Image Statistics and Optimal Edge Detection

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The human visual system has evolved to optimally process the kind of stimuli occurring most frequently in our environment. This adaptation takes place by tuning the shape of receptive fields to the statistical properties of the environment.

In previous work [1] we showed that characteristic properties of the environment are reflected in the shape of receptive fields of cortical simple cells. For three different image classes -natural images showing landscapes, animals and flowers, manmade scenes showing mainly buildings, and aerial images of urban areas- specific receptive fields have been derived by Independent Component Analysis and characterized: receptive fields tuned to natural scenes are sensitive to short contours in various directions, those tuned to manmade scenes are sensitive to short contours which are horizontally or vertically oriented. Receptive fields for aerial images are tuned to long edges in various orientations.

In this work these class-specific receptive fields have been used in conjunction with an edge detector that is based on the human visual system. The edge detector was proposed in [2] and is based on a feedforward model with lateral inhibition. The model parameters were tuned in an optimization step which maximized the distinctiveness of responses for pixels lying on an edge and pixels not lying on an edge. This step was motivated by theories in the field of neural information processing assuming that a neural processing stage transforms its input to a representation which facilitates further processing.

The results of our work show that the edge representation obtained by the simple cell model describes the image structures best if processed with the receptive fields tuned to the appropriate image class. If filters optimized for a different image class are used, only the main edge structure is still detected. For example, applying filters optimized for natural scenes to aerial images results in a representation containing much noise and jitter making further processing very hard. When filtering natural scenes with receptive fields adapted to aerial images, fine details are often not well detected.

In ongoing work the response of the described edge detector is fed to a junction detector. The whole system builds a point of interest detector which is used in conjunction with landmark selection algorithms to detect landmarks in aerial images.

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Perception of Time

The Hierarchy of Brain and Mind

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The general consensus is that the brain is something different from the mind: it is made of physical substance, and is subject to the laws of physics. The mind, however, cannot be described by physical methods. It is considered to be related to experiences such as perceptions or consciousness. The question of the connection between mind and brain, or that of body and soul, is probably the most profound problem at the interface between the “sciences” and the “arts”. That signals can be emitted by the brain and then enter our consciousness—and thus that the brain influences the mind—is hardly in dispute. Indeed, psychophysics is even capable of specifying a quantitative relationship between a physical stimulus and the sensation it elicits. Opinion is more divided regarding the question of whether the mind can also influence the brain. German criminal law presupposes that it does [1], and the sociologist Jürgen Habermas shares this view [2]. The concept that the brain determines the mind is consistent with the laws of physics. But this does not apply to the opposite concept, that the mind can affect the brain: an ability of the “mind” to modify the activity of nerve cells would contradict the principle of causality. Benjamin Libet [3], however, takes the latter concept as a starting point in one of his much-discussed experiments on the question of conscious free will. He measured how long it takes for us to make a voluntary movement after we become aware of the fact that we want to make it, and found that the delay was about 200 ms. Surprisingly, however, brain potentials that indicated the initiation of the movement were measurable more than 500 ms before the movement occurred. The conclusion: the “will” cannot trigger the movement, because it is evidenced 300 ms too late. If the opposite result had been obtained, so that the will to act was apparent prior to the brain activity, the conclusion would have been that this result is indeed consistent with the notion that the “will” initiated the movement. Furthermore, Libet concludes that “conscious control over the actual motor performance of the acts remains possible”. Another interpretation of his results, which however can be reconciled with the laws of physics, is as follows. Brain activity initiates both the activation of the muscles that produce the movement, and also the perception that one is “willing” to make the movement. Which of these processes first becomes apparent has no implications regarding the causal relationships. As long as one takes it as given that laws of physics apply to the brain, the possibility that the “will” initiates movements is ruled out.

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Influence of Vestibular Information on Time Perception

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The time production method is well known to measure time perception. Attention, work load but also physiological factors such as body temperature and hormones are often cited to influence time production. A change of cognitive processing—and so an influence on internal time—under vestibular input and other position related factors like blood pressure on brain is suggested. In this explorative study, influence of vestibular, in particular otolith signals on time production was investigated. In two consequent experiments, conducted on two different days, participants' task was to produce the time intervals of 1s, 3s and 8s. A human centrifuge was used to move the 14 participants in the roll plane. Sex, roll direction, order of intervals and order of position (Experiment 2) were counter-balanced. In Experiment 1 a constant roll velocity of $1.96^\circ/\text{s}$ was used to test the influence of constant varying otolith signals with minimal canal signals. In the experimental condition the participants had to produce intervals during a full rotation for each of the three intervals. Baseline conditions were conducted in the beginning and at the end with no rotation. Experiment 2 was conducted with the same group of participants. In this experiment the difference between static roll positions of 90° , 135° , 180° and 0° in baseline condition were tested. The baselines were again conducted before and after the experimental condition. All intervals were tested in all of the three roll positions. The data show large variation of interval production times between participants. No significant differences between the means of control and constant roll condition were found. In the conditions some participants showed interesting individual effects. In conclusion data should be interpreted on individual base—it seems as if otolith stimulation as well as the duration of a task has got an individual influence on time production.

Perceptual Development

Development of the Detection of Ambiguities in Vision and Speech

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Ambiguities are encountered in language as well as in visual perception. In visual ambiguities, a picture can be interpreted in two different ways, so that two different meanings can be assigned to it. In language there are two major kinds of ambiguities: lexical and syntactical. In lexical ambiguities, two (or more) different meanings can be matched to a single word. Concerning syntactical ambiguities, a sentence can have two (or more) meanings. Perception of both visual and lexical ambiguities emerges during pre-school age and matures in early puberty (Swinney & Prather, 1989; Gopnik & Rosati, 2001). Our aim was to investigate whether the detection of these three types of ambiguities emerge successively or simultaneously. The former would speak for a modal processing of ambiguities, the latter for a general developmental strategy of the brain.

Ninety-four children in 6 age groups (3, 4, 5, 6, 8 and 12 years old) and 12 adult observers were included in this study. The visual ambiguity task consisted of selecting the matching pictures out of four picture cards (two unambiguous figures and two distractors). The lexical ambiguity task consisted of selecting one out of two unambiguous pictures out of four picture cards after hearing the ambiguous word. The syntactical ambiguity task had to be acted with toy figures. All subjects participated in all tasks, in randomized sequence.

There was a general increase in the ability to detect ambiguities with increasing age. Until the age of five years, there was a tendency to detect lexical better than visual ambiguities. Lexical and visual ambiguities diverged from syntactical ambiguities, which showed a much slower developmental course and were still immature at eight years of age. Children aged 8 to 12 years were similar to adult observers for visual and lexical ambiguities, while the syntactic ambiguities did not reach adult level before 12 years of age.

This suggests that the general ability to perceive ambiguities arises earlier in child development than previously supposed (Gopnik & Rosati, 2001). The asynchrony in the development of syntactic vs. perceptual ambiguities speaks for a modal processing, rather than a universal developmental strategy of the human brain. The slower development of perception of ambiguities in sentences might be related to the late development of cognitive structures in the prefrontal cortex, as opposed to the earlier maturation of visual and auditory brain structures, which might be responsible for the processing of visual, respectively lexical ambiguities.

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Language Lateralization in Children using Magnetoencephalography: a New Task to Investigate Hemispheric Dominance

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The question of hemispheric dominance in language has been one of the central topics in neuroscience for many years. Left-hemispheric lateralization of language has been shown in children before predominantly using functional magnetic resonance imaging [1]. The aim of this study was to evaluate paradigms for the assessment of lateralization and for investigating developmental aspects of language perception and production in childhood, using magnetoencephalography (MEG).

In the present study hemispheric dominance for language was investigated with a whole-head MEG. Two language tasks were used: a) In a newly developed Vowel-Identification task, subjects were instructed to identify a vowel (“i”) in the name of a depicted object (e. g., ship -> yes, dog -> no). b) In a commonly used Verb-Generation task, subjects were instructed to generate a matching verb for a given noun (e.g., food -> eat). Ten healthy right-handed adults, all native German speakers, were examined to test these tasks and the lateralization of language functions. Afterwards 22 healthy children, also native German speakers aged 7–16 years and right-handed, were studied using the same tasks to investigate the language development and lateralization as a function of age.

For the adults both tasks showed lateralization of language receptive and productive areas to the left hemisphere, reflected in the reduction of beta-band activity (13–25 Hz). In the case of the children, lateralization was similar to the adult data. In addition, evidence of an age dependent development of language lateralization was detected.

Both tasks reliably lateralized language in this study. Neither paradigm requires high language proficiency, making them suitable for children or patients with a low verbal aptitude. Confirming earlier fMRI-data [2], an increase in activation in language areas during childhood was seen. We therefore believe that MEG is a suitable and valuable adjunct to non-invasively study language organization and development in children.

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Perceptual Neuroscience

Identity Related Responses in the Human Extrastriate Body Area: An fMRI StudyAmra Hodzic,¹ Lars Muckli,¹ Wolf Singer¹ and Aglaja Stirn²¹MPI Frankfurt, ²stirn@em.uni-frankfurt.de

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Evidence indicates functional specialisations of extrastriate areas of the visual cortex for the processing of objects (lateral occipital cortex, LOC), places and scenes (parahippocampal place area, PPA), faces (occipital, OFA and fusiform face area, FFA) and bodies or body parts (extrastriate body area, EBA). Activity in the EBA of the right hemisphere has been found to be stronger for allocentric than for egocentric views of human body parts showing no effect of identity [1]. Here we investigate whether activation patterns differ for the perception of one's own body and the body of others. To this end we presented images of bodies (without head) that represented either the subjects themselves (condition self), other persons of either sex (condition others same sex, and others opposite sex), inanimate objects and scrambled objects in a block design. We identified EBA as the region activated in response to the comparison bodies > objects. Using ROI based analysis we compared activation within the EBA-ROI and between conditions self and others. We found significantly stronger activation in the occipito-temporal EBA in the right hemisphere for the condition self compared to the condition others. In the left hemisphere less pronounced self modulated activity was also observed in the EBA. The other brain areas showing self-identity related activity, besides right and left EBA are: intraparietal sulcus and superior parietal lobe of the right hemisphere. The strongest self modulated activity was found in the regions of the right hemisphere indicating right hemisphere dominance in self others distinction. We propose that right and left EBAs are bodies selective regions. Their occipito-temporal components are robustly devoted to the distinction between self and others together with the intraparietal sulcus and superior parietal lobe of the right hemisphere. The activation of EBA and additional areas in distinction between self and others is compatible with the notion that self-identification involves a network of cortical areas.

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Visual Form Agnosia after Medial Occipital Temporal Lesions Sparing LOC.

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Perception-related visual information processing is presumed to occur in a ventral, action-related visual processing in a dorsal stream of cortical areas. This distinction between two anatomical streams is essentially based on the observation of a double dissociation between deficits of object perception and deficient visuomotor coordination in brain-damaged humans. The inability to direct spatially accurate movements towards visual targets while accurately perceiving features like shape and orientation is known as optic ataxia. Conversely, the inability to accurately perceive features like shape and orientation of an object while being able to act on these features is known as visual form agnosia. A considerable body of evidence is based on observations in only one brain-damaged patient (DF). She suffered an extended damage of the bilateral occipital, parietal, and temporal cortex due to an anoxic event and subsequent atrophy. Nevertheless, it has been suggested that particularly the lateral occipital complex (LOC) represents the crucial correlate of her remarkable deficits. We investigated a patient (JS) with a well-defined medial bilateral occipito-temporal brain damage. His behavioural results were strikingly similar to the results of DF, revealing the same dissociation of action and perception. However, in contrast to DF the deficits in JS were not caused by an anoxic event leading to wide spread diffuse brain damage. Rather, it was caused by a single stroke resulting in a circumscribed bilateral medial occipito-temporal lesion sparing the lateral aspect of both hemispheres. Comparing the behavioural outcome and the lesions of DF and JS we conclude that a lesion in the lateral occipital complex is not sufficient to explain the remarkable perceptual deficits and behavioural dissociation between visual perception and action control. This conclusion calls for a new anatomical definition of the proposed ventral stream of visual processing and offers new approaches for further functional investigations of the respective structures.

Cortico-Cortical Connectivity: Measurements on Distant Axonal Arbours of Pyramidal Cells in the Mouse Neocortex

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The axons of pyramidal cells have usually both local collaterals in the vicinity of their dendritic tree and distant terminal ramifications. Via their distant axonal arbour pyramidal cells connect to other brain regions or—in the majority of cases—to other regions in the cortex. In earlier work, we have made estimates on the length of axonal arbours of individual pyramidal cells, including both local and distant parts [1]. In the present study we measured the length of distant terminal arbours of pyramidal cells stained by extracellular injections with the anterograde tracer biotinylated dextran amine (BDA).

We scrutinized our BDA-material for isolated axonal arbours which were far away from the injection site. The ramifications of 10 such terminal arbours (7 ipsi-, 3 contralateral to the injection site) were traced under a microscope connected to a computer system (Eutektit), and the diameters of the axonal arbours and the total length of fibres of each arbour within the section were measured.

The axonal arbours had diameters between 0.12 mm and 0.35 mm. The measured lengths within a section of a thickness of 0.05 mm ranged between 0.87 mm and 2.19 mm, with an average of 1.55 mm.

These measurements have to be corrected for the fibres not contained in the section. Such a correction can be based on the observation that the terminal ramifications measured in this study appear to be distributed in a cone-like volume and on the assumption of a symmetrical spread outside the section. Preliminary results indicate that such a correction increases the values to an average length of about 9 to 11 mm (including the ascending main axon). This is compatible with estimates of the total length of axon produced by an average pyramidal cell in the mouse cortex (10–40 mm) [1]. The data will be compared to measurements in the literature on other species.

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Tactile Perception

Psychophysical Assessment of Distortions in Heat/pain Somatotopy after Sensitisation of the Skin

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Heat pain stimuli can be localized almost as accurately as tactile stimuli [1,2] and their somatotopic representation appears to be organized in a similar manner. The localization accuracy of tactile innocuous and painful stimuli is known to be impaired by transient induction of skin hyperalgesia by capsaicin [3]. We hypothesized (a) that this impairment can also be observed for heat stimuli activating nociceptive pathways, and (b) that the somatotopic representation of the body surface will be distorted due to the increase in sensory input from the affected area.

We used CO₂ laser stimuli to assess somatotopic representations of thermal-nociceptive stimuli, first on normal skin and then after sensitising the skin by the topical application of capsaicin (1 % solution cream) for 30 minutes. Thirty-four stimulus locations were arranged on two lines of 160 mm length on the right dorsal forearms (N. radialis area, C7 dermatome) of eleven healthy subjects. Each location was stimulated twice in a pseudo-randomized sequence, both in the baseline and in the capsaicin condition. Subjects were instructed to mark the perceived locations with a 3D tracker without touching the skin, and position indications in distal-proximal direction were analyzed.

The overall displacement of perceived from physical locations increased significantly (Wilcoxon Signed-Rank test, $p < .001$) from baseline (mean: 23 mm, SD: 18 mm) to sensitisation condition (mean: 27 mm, SD: 23 mm). Capsaicin led to a decrease in the amount of variance explained by subject-wise linear regressions (average adjusted R²: .69 vs. .83). A significant group-wise decrease (Wilcoxon Signed-Rank test, $p < .05$) in the slopes of individual regressions between physical and perceived positions due to capsaicin indicated a ‘compression’ of the spatial representation.

Our results demonstrate a decrease in localization accuracy accompanied by distortions in the spatial representation following capsaicin-induced sensitisation of the skin. While still having a fairly accurate somatotopic representation, subjects tend to localise stimuli in a smaller range, possibly reflecting increases in dorsal horn neurons receptive fields.

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An MEG Paradigm to Study the Cortical Processing of Near-Threshold Tactile Stimuli

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The processing of near-threshold tactile stimuli has so far primarily been investigated in psychophysical experiments. The findings of these studies suggest that, although these stimuli are not consciously perceived, they are still, to some extent, processed on a cortical level. With this experiment we aimed to develop a paradigm that allows the investigation of cortical activation due to near-threshold tactile stimuli by means of neuromagnetic imaging (151 channel whole-head MEG). Since somatosensory evoked responses to single near-threshold stimuli are too weak to be recorded by MEG, we chose an indirect approach to demonstrate cortical processing of weak stimuli by investigating the effect of near-threshold stimuli on the cortical processing of succeeding strong tactile stimuli. We hypothesized that weak stimuli would lead to amplitude modification of early somatosensory evoked responses of the second stimulus. We presented pairs of tactile stimuli, consisting of a strong stimulus preceded by either a near-threshold (NT), a strong (2S) or no stimulus (1S), to the subject's left index finger. In order to determine the stimulus onset asynchrony with maximum effect, we varied the SOA (200, 350, and 500 ms). Cortical responses of the NT condition were separated in sub- and supraliminal trials according to the reported number of stimuli subjects perceived per trial. In comparison to the presentation of a single strong stimulus (1S), somatosensory evoked responses to stimuli that were preceded by a second stimulus (conditions 2S, NT supra and NT sub) showed significant reduction in amplitude. This reduction in amplitude was restricted to the second component of the cortical response that occurred 90–120 ms after the second stimulus. The effect was strongest for the 2S condition. For the NT conditions, detection of the first stimulus didn't have a significant effect on the extent of amplitude reduction. Furthermore, there was no significant SOA effect. The experiment reveals that weak, undetected tactile stimuli lead to cortical activation, which influences the somatosensory cortex up to 500 ms. Thus, conscious perception of tactile stimuli seems to be subject to higher cortical areas.

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Visual Cognition: General

The Influence of Camera Height on the Recognition Performance of a Dynamic Scene

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The focus of interest of the reported experiments is the examination of the influence of the camera height on recognition performance of a dynamic scene. Due to the literature there are at least two different possible views on a scene: gaze and survey. While a gaze view is obtained by looking into a room from the door, a survey view can be obtained by looking at a room from its ceiling [1].

In the first study it was hypothesized that using a survey view in the learning phase leads to (a) higher and (b) a more viewpoint independent recognition performance. Dynamic scenes, consisting of for different colored balls of different velocities were used as stimulus material. In the learning phase they were either presented in a gaze or a survey view. In the test phase video stills of the previously seen and of a distractor scene were presented both in gaze and survey mode taken from different horizontal viewpoint deviations at different points of time. Although the analysis of the sensitivity measure showed no viewpoint deviation effect, neither horizontal nor vertical, there was a significant interaction between camera height in the learning and testing phase and the point of time. During the learning phase watching a video clip in a gaze view, leads to higher recognition performance for late points of time compared to watching a video clip in a survey view.

The second study addresses the question whether the failure of proofing the viewpoint deviation effect is due to the use of survey views in the learning or test phase. Studies using static scenes as stimuli, found a viewpoint deviation effect for vertical deviations [2]. In this study it was assumed, that there is a vertical viewpoint deviation effect also for dynamic scenes. The same dynamic events as in study 1, dynamic scenes were used as stimulus material. They were either presented from a gaze or survey view. In a recognition test participants were presented video stills of the seen scene or of a distractor scene, showing different points of time of the scene with vertical viewpoint deviation. The analysis of the sensitivity measure shows no vertical viewpoint deviation effect. Taken together, the reported studies suggest that there is an advantage of gaze views compared to survey views in the recognition performance. In contrast to static scene recognition there is no viewpoint dependency for vertical viewpoint deviation at dynamic scene recognition.

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Head and Eye Movements in a Widespread Stimulus Comparative Search Paradigm

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From recent studies it is known that the capacity of visual working memory is very limited. This has been shown by research on a phenomenon called change blindness [1]. Also results of the block copying task [2] show that subjects performed additional eye movements to minimize memory demand. From this it follows that there is a trade-off between the use of working memory and eye movements based on their cost to optimize the visual performance. With this assumption increased costs for eye movements should lead to an increase of memory use.

To investigate this, we used a comparative visual search task (CVST) with stimulus size as independent variable. Widespread stimuli should induce larger gaze (head and eye together) shifts and therefore higher costs with regard to gaze movements. We performed experiments in a virtual reality environment and presented the visual stimulus on a curved, tilted, conical screen with a field of view of 150° in horizontal and 70° in vertical direction. The subjects sat in front of the projection screen (distance: 1.6m) with a head mounted, infrared light based eye tracker. Furthermore we measured head movements. 12 subjects participated to this experiment (age: 23–34 years).

For the CVST we presented two shelves, filled with colored objects. The subjects had to compare both shelves to find differences between the object constellations. We used three different constellations: zero targets (both shelves were identically), one target or two targets. To induce larger gaze movements, we used four different shelf distances in randomized order (30°, 60°, 90° and 120°).

For all four distance conditions, there were no differences in the error rate to detect the correct target amount. We found the same amount of fixation number for all four shelf distances. The fixation duration was significantly increased for larger stimulus size (from 246.7 ± 151.8 to 267.6 ± 190.5 ms) and we found a significant reduction of gaze shifts between the two shelves.

This results indicate the use of working memory if larger and thereby costlier gaze shifts are necessary.

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The Verbal Overshadowing of Dynamic Scenes: The Influence of Source Confusion.

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The effect of verbalization processes on memory has been widely explored during the last years. If subjects were asked to verbalize a certain object of a scene (e.g. a face), visual recognition performance is worse compared to a control condition, where no verbalization processes were applied [1]. One study even shows a verbal overshadowing effect, when the participants received the verbalization passively. It was argued, that this is because of source confusion about the validity of the representation (visual or verbal), which can be reduced by instructing the participants to ignore the verbalization [2]. Besides the question whether the verbal overshadowing effect occurs during verbalizing dynamic scenes, the focus of this study was the question whether the mentioned confusion can be reduced using different distractor types: distractor items can either be designed in line with the verbal summary (event model compatible), or they can be designed that they contradict the verbal summary (event model incompatible). In this study dynamic scenes consisting of four balls with different colors and velocities were used as stimulus material. Different verbalization conditions were realised: film only vs. verbal only vs. film + verbal. In the film condition the participants watched only a film plus a filler task; in the verbal condition they only viewed a verbal summary of a dynamic scene. In the film + verbal condition the participants viewed a verbal summary of the film they viewed before. In all conditions the participants had to accomplish a visual recognition test which included pictures of the seen and pictures of two types of distractor scenes: event model compatible and event model incompatible. In the film + verbal condition it was expected that event model incompatibility reduces confusion and weakens the verbal overshadowing effect, while event model compatibility should lead to a classic verbal overshadowing effect in the film + verbal condition. The analysis of the sensitivity measure showed a significant verbal overshadowing effect. If a verbal summary is provided after the film, recognition performance impaired. In addition there is a significant interaction between verbalization condition and event model compatibility, participants performed worse in the film + verbal condition than in the film condition even at event model incompatibility. Taken together the results of this study indicate that there is a verbal overshadowing effect for dynamic scenes.

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The Role of Motion in Natural Scene Processing Revealed by Visual SearchQuoc C. Vuong¹ and Ian M. Thornton²¹MPI for Biological Cybernetics, Tübingen, ²University of Wales Swansea

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There is a large amount of movements in the environment but only some are relevant to an observer, as these indicate objects of interest (e.g., prey or predator). In a previous study, we found an advantage for detecting dynamic targets (e.g., humans) compared to static ones in visually degraded natural scenes. Here we used a visual search paradigm to investigate the role of motion in the perception of natural scenes across different target categories and without image degradation. Observers were presented with a circular array of 2, 4, 6 or 8 natural scene movies. These scenes were selected from three categories: human actions, animal movements, and machine movements. The objects in these different categories differed in their shape and movement patterns. The observers' task was to search for a target category among distractors from another category. In Experiment 1, observers searched for human targets among machine distractors on one block and machine targets among human distractors on another block. The block order was counterbalanced across observers. In Experiment 2, we used animals and machines in the same design. Lastly, in Experiment 3, we used humans and animals. Across all experiments, search times were affected by set size. Importantly, we found that observers were faster at searching for humans and animals among machines than they were at searching for machines among either of these distractor categories (Experiments 1 and 2), suggesting that biological motion facilitated search. However, there was no difference in search times for humans and animals (Experiment 3), suggesting that human and animal movements are treated equivalently by the visual system. Overall, the present results point to the importance of a high-level interpretation of motion (e.g., as biological versus mechanical motion) in processing natural scenes.

Visual Cognition: Objects and Faces

Recognizing Dynamic Object Across Viewpoints

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Recognizing objects across viewpoints presents the visual system with an extremely challenging task. This would be particularly true if learned representations were solely determined by spatial properties. However, a number of recent studies have shown that observers are also highly sensitive to characteristic object motion. Could the availability of characteristic spatial-temporal patterns in the natural environment help explain the ability to generalise across viewpoints? Here, we examined how familiar object motion (both rigid and nonrigid) improves object recognition across different viewpoints. In both experiments, participants were first familiarised with two novel dynamic objects from a fixed viewpoint. These objects presented the observer with a coherent sequence of change that had a unique temporal order, resulting from either rotating a rigid object about the horizontal axis (Experiment 1) or through a characteristic deformation of a nonrigid object (Experiment 2). Subsequently, participants were tested for their ability to discriminate these learned objects from new distractors using a 2-interval-forced-choice task. During test, objects were presented at 0°, 10°, 20° and 30° around the vertical axis relative to the learned viewpoint, and in the learned or reversed temporal order. Motion reversal is a common manipulation used to disrupt spatiotemporal properties, without interfering with the object's spatial characteristics. In both experiments, accuracy decreased with increasing variance from the learned viewpoint. Nonetheless, objects were consistently better recognised when presented in the learned motion sequence (mean accuracy: Expt 1 = 86%; Expt 2 = 81%) compared to the reverse motion condition (mean accuracy: Expt 1 = 81%; Expt 2 = 76%), across all viewpoints tested (Expt 1: $F(1,23)=13.94$, $p<0.01$; Expt 2: $F(1,23)=8.78$, $p<0.01$). These results indicate that both rigid and non-rigid motion facilitated object recognition despite disturbances in 2D shape by viewpoint changes.

Virtual or Real? Judging The Realism of Objects in Stylized Augmented Environments

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In augmented reality, virtual graphical objects are overlaid over the real environment of the observer. Conventional augmented reality systems use standard computer graphics methods for generating the graphical representations of virtual objects. These renderings contain the typical artefacts of computer generated graphics, e.g., aliasing caused by the rasterization process and unrealistic, manually configured illumination models. Due to these artefacts, virtual objects look artificial and can easily be distinguished from the real environment.

Recently, a different approach to generating augmented reality images was presented. In stylised augmented reality, similar types of artistic or illustrative stylisation are applied to the virtual objects and the camera image of the real environment [1]. Therefore, real and virtual image elements look more similar and are less distinguishable from each other.

In this poster, we describe the results of a psychophysical study on the effectiveness of stylised augmented reality. A number of participants were asked to decide whether objects shown in images of augmented reality scenes are virtual or real. Conventionally rendered as well as stylised augmented reality images and short video clips were presented to the participants. The correctness of the participants' responses and their reaction times were recorded. The results of our study clearly show that an equalized level of realism is achieved by using stylised augmented reality, i.e., that it is distinctly more difficult to discriminate virtual objects from real objects.

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Involvement of the Temporo-Parieto-Occipital Junction (TPOJ) in Global Gestalt Perception

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The integration of individual features is a fundamental process for the intact perception of a global scene. Disturbance of this process has been found in patients with Blint's syndrome following bilateral damage of the parieto-occipital cortex. However, the cortical mechanisms underlying grouping processes remain largely unknown. In an event-related fMRI study, we investigated the neural correlates of spatial integration of visual features in healthy subjects. We compared the observed neural activity with the psychophysical performance and tested for attentional modulation of the fMRI responses. The stimuli consisted of images of circles or squares (global level) rendered by smaller images of stimuli from these categories (local level) resulting in four combinations: a) global circle, local circle; b) global circle, local square; c) global square, local circle and d) global square, local square. Furthermore, we parametrically degraded the objects at the global level by exchanging the smaller images of objects at the local level with each other resulting in the following conditions: 1) Intact Global Perception at 20%-Scrambled, 2) Reduced Global Perception at 40%- Scrambled, 3) Reduced Global Perception at 60%- Scrambled and 4) Disturbed Global Perception at 80%- Scrambled. Subjects were engaged in a 2AFC-task on the category at the global (Experiment 1) or local (Experiment 2) level. The fMRI responses of Experiment 1 revealed a network of cortical areas to be involved in the spatial integration of visual features including the precuneus (PC), anterior cingulate cortex (ACC) and the temporo-parieto-occipital junction (TPOJ). Strong relation between neural activity and psychophysical performance was found for TPOJ but not PC and ACC. In contrast, no significant differences across conditions were observed in the fMRI responses of Experiment 2. These results suggest an involvement of the TPOJ in the spatial integration of visual features.

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Internal and External Facial Features Differentially Bias Person Recognition—An Approach using Animation TechniquesKarin S. Pilz,¹ Heinrich H. Bühlhoff¹ and Ian M. Thornton²¹MPI for Biological Cybernetics, Tübingen,²Department of Psychology, University of Wales, Swansea

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When a person approaches you, there are multiple cues that could help you to identify that person, such as their face, hairstyle, clothes or walking pattern. Currently we are using animated figures to explore the differential impact of these cues on person recognition. Here we mainly concentrate on the face as a cue to identity and especially the influence of external and internal facial features on recognition performance. Internal facial features refer to the size and outline of the eyes and mouth and their configuration. External facial features rather denote the shape of the face or the hairstyle associated with a particular face. We use 3D graphics and computer animation to explore the impact of such sources of information. Animation techniques allow us to modify some features, while keeping other features constant, e.g. the body or walk pattern. As stimuli we attached faces from the MPI face database to 3D body models from POSER and animated them with a simple walk as if approaching the observer. In a learning phase, observers studied two static targets that only differed in their facial features. Hairstyle and clothing were kept constant. In a later recognition task, these two targets were moving towards the observer, who had to identify them as quickly and accurately as possible. During this recognition task, we varied hairstyle and specific clothing to test which kind of external features impair recognition performance most. Our results show that for close-up recognition observers seem to rely more on internal facial features, whereas they are highly influenced by external factors, i.e. hairstyle, when a person is further away. These findings provide additional evidence that external facial features are important for recognizing unfamiliar faces.

Mental Rotation of Human Figures in the Picture and Depth Plane

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How do participants solve mental rotation tasks of human figures? We assume that participants use different strategies depending on the orientation of the stimulus and the axis of rotation as reported in earlier mental rotation studies (Parsons, 1987 [1]; Murray, 1997 [2]). This study is part of a series of experiments using a classic left/right decision tasks. Similar to Zacks, Mires, Tversky & Hazeltine (2000 [3]) participants were asked to decide whether the left or the right arm of the body figure is sprawled out. Stimuli always appear either in a front or back view at random orientation (0° , 45° , 90° , 135° , 180° , 225° , 270° , 315°). Body figures were presented in two different rotation conditions: picture plane and depth plane. Instead of line drawings of human bodies (as those used by Parsons, 1987 [1]) we used pictures of a photorealistic rendered male body created by a 3D figure design program (Poser 6) allowing stimuli rotation in depth plane.

In contrary to the findings of Zacks et. al (2000 [3]), reaction times are perspicuously shorter in our experiment and data indicate a clear effect of orientation. Our results show a significant view effect presuming different mental transformation processes when stimuli are presented from the front or back. Participants also report using different strategies while performing the tasks (e.g. flipping vs. spinning, Murray, 1997 [2]). Particularly with regard to the 180° position where some of the participants said, they either just mentally flip stimuli to upright or their own body from upright to the 180° stimuli position. Nevertheless reaction time (RT) does not support corresponding statements. Observable is the the difference regarding RT peak in the two conditions. If considering deviations from the upright position (0°), there is a significant interaction effect between orientation and plane and in contrary to the picture plane a strong asymmetry is found for rotations in the depth plane.

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Generation of Sketch-Like Feature Encodings in Oriented Faces—A Neural Model

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Identity-independent estimation of head pose from single images across a wide range of pose angles is a difficult task since 3D rotation of the head leads to strong non-linearities in the appearance of faces. Feature-based approaches utilize the geometrical configuration of facial features to determine the pose of faces [1]. Nevertheless, when the face is rotated in depth, distinct features such as eyes, nose or mouth may partly be occluded or disappear completely. Given the changes in visibility and appearance of facial features at different head poses it remains largely unclear which features play the most significant role in pose estimation. In this contribution, we present a neural model that creates an abstract representation of perceptually relevant features from single images of oriented faces. The major stages and dynamics of the model can be summarized as follows: (i) Oriented contrasts are detected utilizing oriented band-pass filters (e.g., Gabor filters), followed by local competition to normalize activity pattern. (ii) Locally collinear features are grouped and enhanced by integrating context information from the field of extracted orientations, again followed by lateral competition for activity normalization. (iii) Recurrent modulatory feedback [2] from the output of the grouping stage to initial responses in (i) iteratively accentuates filter responses which comprise the smoothly curved flow patterns of image orientations. The model output can be visualized as a sketch-like drawing of a face emphasizing important pose specific features. Our results demonstrate that perceptually relevant structures such as collinear orientation pattern (Gestalt laws) are enhanced after a few iterations of feedback. Regions that do not match this rule are weakened by this operation. Thus, the amount of possible feature candidates is reduced over time. To evaluate our model we use the sketch representation as basis for existing feature-based head pose algorithms [3]. In conclusion, our approach not only provides a tool for visualizing important features of faces, it also yields a sparse representation of faces which can be directly integrated into face recognition tasks.

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[2] Neumann & Sepp, 1999, *Biological Cybernetics* 81

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Visual Cognition: Space Perception and Navigation

Path Planning and Optimization in the Traveling Salesman Problem

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The complexity of path planning tasks grows quickly with the number of targets. Human navigators, however, usually solve route planning tasks fastly and efficiently. Here two experiments are presented that study the role of nearest neighbor strategies and region-based strategies for path planning. For this, subjects were repeatedly asked to solve traveling salesman problems (TSP), i.e. to find the shortest closed loop connecting a given start place with a number of target places. For each TSP, subjects were given a so-called ‘shopping list’ depicting the symbols of the start place and the target places. While the TSP is computationally hard, sufficient solutions can be found by simple strategies such as the nearest neighbor strategy. In Experiment 1, it was tested whether humans employed the nearest neighbor strategy (NNS) when solving the TSP. Results showed that subjects outperform the NNS in cases in which the NNS did not predict the optimal solution, suggesting that the NNS is not sufficient to explain human route planning behavior. As a second possible strategy a region-based approach was tested in Experiment 2. When optimal routes required more region transitions than other, sub-optimal routes, subjects preferred these sub-optimal routes. This result suggests that subjects first planned a coarse route on the region level and then refined the route during navigation. Such a hierarchical planning strategy would allow to reduce computational effort during route planning. In a control condition, the target places were directly marked in the environment rather than being depicted on the shopping list. As subjects did not have to identify and remember the positions of the target places based on the shopping list during route planning, this control condition tested for the influence of spatial working memory for route planning performance. Results showed a strong performance increase in the control condition, emphasizing the prominent role of spatial working memory for route planning.

Verbal, Visual and Spatial Memory in Wayfinding

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This study examined the working memory systems relevant for wayfinding. 24 participants learned two routes in a novel photorealistic virtual environment displayed on a 220° screen while performing a verbal, a visual, a spatial or no secondary task. Performance in the secondary task and in subsequent retracing of the previously presented routes with a joystick was recorded. Participants without a secondary task performed better compared to participants with a secondary task. On one route participants with the visual secondary task got lost less often compared to participants with the verbal secondary task. Better performance in the visual secondary task was found compared to the spatial secondary task. A trade-off between first and secondary task could be ruled out. The results indicate that spatial and verbal memory were used in wayfinding. Despite other results in pre-tests we measured a non-significant higher difficulty of the spatial secondary task in a baseline condition, providing an alternative explanation for the importance of spatial memory.

After the experiment we tested the participants' memory for their local surroundings. In a choice reaction task presented on a computer screen they had to discriminate pictures of intersections they had encountered before from distracters. Intersections encountered before were discriminated faster and more accurate from distracters when the perspective seen was along the direction of travelling compared to 90° or the opposite direction. The participants encoded their local environment view-dependent as they encountered it. At the level of large scale spaces, this result contradicts with encoding spatial information relative to a single reference direction [e.g. 1]. Pictures taken along the direction of travel were recognised better and faster than pictures aligned with a reference direction defined by the initial direction or the main orientation of the environment.

In agreement with studies in reorientation [e.g. 2], verbal memory was used for wayfinding. These results are consistent with a dual coding approach, which states that spatial information is also encoded verbally. Local intersections were stored view-dependent as experienced along with the direction of travel rather than parallel to the initial orientation or the main orientation of a route.

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Quality and Barrier-Effects in Pointing in Reality and in VR of “Kindergarten” Childs

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It is general accepted that the possibility to orient and navigate in large scale urban areas develops, like all other intellectual capabilities, in the course of growing up. Uncertainty exists on the exact steps of that development and on the influence of individual experiences within that course. It may be possible too that there are critical time-windows in the child development in which experience is able to establish special knowledge.

We performed experiments with “kindergarten” children of the age of 4 in a large-scale urban environment that was unknown to the experimental subjects. The task for the subjects was to point from different positions of the terrain towards a goal that was shown to them at beginning of the experiment. The test-points are positioned on free places in the terrain or near the walls of buildings. The experiment was performed twice. One takes place in the reality of our university campus, the other was performed in the VR “NeuViberg” a 180 degree visual field projection of a 3D representation of the campus with the possibility to navigate through the VR walking as a pedestrian using a treadmill.

We asked the children which experiences they had in exploring their living neighbourhood for their own and whether they used to play computer games.

The results show for the 4 years old children a sometimes precise ability of pointing to the invisible goal in the reality. The results of the experiments in the VR are worse. In both experiments we get a clear barrier-effect. This is a hint that orientation and navigation in virtual realities need a higher degree of abstraction that is developing in later stages of growing.

Robust Visual Navigation using Optical Flow Fields in Dynamical Environments

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Our work focuses on the visual navigation biologically plausible for autonomous mobile robot tasks. The main effort is set in finding efficient solutions for different navigation tasks related to mobile robots, such as obstacle avoidance, scene-based homing, path integration, and more. The basis of this research is to estimate an optimal optical flow field, that is, the robot's motion relative to its surroundings. Optic flow is used by some insects, such as flies and bees, which show a very effective navigation capacity. For that we are going to use the well-studied Lucas Kanade method that has shown to be among the most accurate and more reliable of the methods to perform [1]. Once a reliable optic flow field has been estimated the own motion can be calculated [2] and later on one can apply the different navigation tasks mentioned above. The novelty of the work is to extend the application to an outdoor environment, where the main problem is to distinguish between the optic flow generated by our own motion and the one generated by independent moving objects. Our goal is to use only the visual information for the mobile robot navigation tasks mentioned above in dynamical environments.

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Visual Perception: Colour

Sensorimotor Adaptation in Colour

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Sensorimotor adaptation can be defined as a perceptual adaptation whose effects depend on the occurrence and nature of the performed motor actions. Examples of sensorimotor adaptation can be found in the literature on prisms. This literature has contributed to establish the role of action in the perception of space-related attributes like orientation, curvature, size or depth and it is now common to think that space perception involves adaptable sensorimotor mechanisms. On the other hand, until recently, the influence of action on color perception had never been successfully addressed experimentally. In a series of experiments, Bompas & O'Regan (2006a, b) showed that sensorimotor adaptation could be easily obtained for color, as a consequence of the introduction of a new sensorimotor contingency between eye movements and color changes. In an adaptation phase, trials involved the successive presentation of a red patch on the left and a green patch on the right. This adaptation stage introduces a correlation between left-right (respectively right-left) eye saccades and red-green (respectively green-red) color change. Perceptual consequences of this adaptation can be measured thanks to a test stage, performed before and after the adaptation. Schematically, the results show that, after 40 minutes of adaptation, when two yellow patches are successively presented on each side of the screen, the left patch needs to be reddish and the right patch greenish for subjective equality to be obtained. Similar sensorimotor adaptation has also been shown for blue-yellow and luminance variations. The dependency of the effect to the properties of the eye saccade (departure position, size and orientation) has now been characterized. These results constitute clear evidence for a role of experience and eye movements in perceived color and argue for the involvement in color perception of mechanisms continuously tuned to sensorimotor contingencies. The relation of these experimental findings towards a sensorimotor theory of color perception will be discussed.

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Color Perception of Transparent Substances

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With transparent substances of varying thickness, the visual system fails to extract color as a subjectively invariant property of the substance from the objectively invariant but high-dimensional absorption spectrum of that substance. Neither brightness nor saturation nor even hue stay the same as the thickness of the layer and/or the concentration changes. Even worse, the hue does not only change within a limited range but can vary once around the entire cyclical hue range, as can be demonstrated with well-known substances such as chlorophyll. The present poster demonstrates the effect by means of pumpkin seed oil. We present experimental data on color perception of this liquid that show that memory color does not reflect the ambiguity of the hue of this liquid: most participants named green as their memory color for pumpkin seed oil. This changes if participants are allowed to experiment with the liquid during the interview. We analyze the hue change in terms of extinction spectra and cone sensitivity functions. The findings are relevant to the topical debate on the existence of objective color.

Discrimination of Synthetic Chromatic Distributions which Resemble Natural Distributions

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In a previous study we found that chromatic discrimination thresholds for natural objects in the adaptation point were elevated compared to thresholds for homogeneous colored stimuli and that threshold contours were elongated in the direction of the chromatic distribution of the object [1]. Here we used synthetic stimuli with different chromatic distributions to investigate to what extent the observed threshold elevation for natural objects can be attributed to the underlying chromatic distribution. With regard to the assumption that the color distribution of natural objects might be similar to a pink noise distribution we measured discrimination for pink noise (noise with a $1/f$ amplitude spectrum). Since we found that the amplitude spectrum of the surface of the natural objects that were used in the foregoing experiment resembled a brown noise distribution, we also measured discrimination for brown noise (noise with a $1/f^2$ amplitude spectrum). In a 4AFC experiment, four stimuli were presented on a CRT monitor in a 2×2 arrangement for 500 ms. Three of these stimuli were identical (test stimuli). The fourth stimulus (comparison stimulus) differed in color. The observers' task was to detect the odd one out. Thresholds were measured for homogeneous colored disks and for the noisy chromatic distributions. The chromaticity of these distributions varied between two points in the isoluminant plane of the DKL color space with an amplitude of 0.25. Discrimination was tested in the adaptation point for stimuli whose chromatic distribution varied along a chromatic direction of 0° , 45° , 90° and 135° in the isoluminant plane. All stimuli were presented against a homogeneous gray background which defined the adaptation point. An interleaved staircase procedure was used to determine discrimination thresholds. Ellipses were fitted to the threshold contours. For brown noise, we found an elevation of thresholds compared to the homogeneous colored stimuli and an elongation of the discrimination ellipses along the noise direction of the stimuli. This was true for all directions of the chromatic distribution. These results are in accordance with the findings for natural objects. For the pink noise chromatic distribution this effect was not as clear as for the brown noise. We conclude that chromatic distributions which vary at low spectral frequencies (brown noise, fruit surfaces) lead to a characteristic threshold elevation which closely follows the direction of the highest chromatic variation.

[1] Hansen, Th. and Gegenfurtner, K. R. (2005): TWK 2005, 149

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Geometric-Optical Illusions at Isoluminance

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Livingstone and Hubel [1] claimed that some visual illusions vanish under conditions of isoluminance. Since the spatial characteristics of early processing in the retina and LGN are distinct, one could expect that some illusory effects would be reduced or even absent under isoluminance. Li and Guo [2] investigated four so-called geometric-optical illusions under conditions of luminance and isoluminance but failed to find any effects of condition. As a consequence of these ambiguous results, we here wanted to investigate a large number of geometric-optical illusions more systematically. The question was whether geometric-optical illusions occur under the condition of isoluminance or not and if so whether this effect is equally strong compared to the luminance condition. For ten illusions (Bisect-, Delboeuf-, Ebbinghaus-, Hering-, Judd-, Müller-Lyer-, Poggendorff-, Ponzo-, Vertical-, and Zöllner-Illusion) five physical variations were created. Stimulus 3 of each series represented the original illusion. Stimuli 1 and 2 enhanced whereas stimuli 3 and 4 reduced the illusory effect. In a 5-AFC paradigm subjects had to choose in which of the simultaneously presented stimuli they subjectively perceived equal length, size or orientation (depending on the kind of variation in the illusion). Each configuration was presented four times under conditions of luminance (black-white) and isoluminance (red-green). 18 subjects with normal color vision participated. The main finding of this study was that all subjects showed the illusory effects under both conditions (luminance and isoluminance) for all ten illusions tested. However, significant differences between the amounts of illusory effect were obtained in some of the illusions. Three showed a stronger illusory effect in the luminance condition and one was stronger in the isoluminant condition. Since the illusory effects were still quite strong in both conditions, the data do not support an assumption of different stages/ pathways of processing for these illusions.

[1] Livingstone, M.S. and Hubel, D.H. (1987): *J. Neurosci.* 7, 3416–3468

[2] Li, C.-Y. and Guo, K. (1995): *Vis Res.* 35, 1713–1720

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Statistics of Chromatic Edges in Natural Scenes

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In the traditional, simplistic view, edges are processed by orientation-selective neurons driven by a pure luminance pathway, whereas the processing of color was thought to be limited to un-oriented neurons. Recent neurophysiological recordings have shown that this strict dichotomy is inadequate: orientation-selective neurons sensitive to a combination of color and luminance exists in the primary and secondary visual cortex [1–3]. Here we present further evidence for the joint processing of luminance and color from the statistical analysis of the distribution of chromatic and luminance edges in natural scenes.

The analysis is based on 764 images from a publically available data base of calibrated color images [4]. The calibrated images are first transformed into LMS cone space, modeling responses of the L, M and S cones of a human observer. Next, LMS responses are transformed into a color-opponent space, with three axes sensitive to luminance “black-white”, L-M “cherry-teal” and S-(L+M) “purple-chartreuse”, resembling the chromatic preferences of retinal ganglion cells and LGN cells. Edges are detected in these three color-opponent planes after normalizing each plane to the range [0, 1], and the joint histogram of edges strengths is computed.

The joint histogram of luminance and L-M edges has a high excursion along the luminance axis and also strong isoluminant L-M edges. However, the large majority of edges do not fall on either axes, and is comprised of both luminance and chromatic contrast. A similar joint histogram occurs for the luminance and S-(L+M) edges, with less pronounced isoluminant edges. Inspection of edge maps in individual images reveals that some prominent object boundaries that are weak or missing in the luminance edge map are clearly delineated in the L-M plane. For example, red fruits or flowers against green foliage, that are hardly visible in the luminance plane, give rise to strong object boundaries in the L-M plane.

Object boundaries are not always characterized by pure luminance variations. Instead, most edges are characterized by a co-occurrence of chromatic and luminance contrast. Further, some prominent object boundaries are signaled robustly only in the chromatic L-M plane. This suggests an important role for color in the detection of object boundaries. The neural networks in early visual areas seems to be perfectly adapted to the joint occurrence of luminance and chromatic edges in natural scenes.

- [1] Johnson et al. (2001): *Nature Neuroscience*, 409–416
- [2] Johnson et al. (2004), *J. Neurophysiol*, 91, 2501–2514
- [3] Kiper et al. (1997), *Vis. Neurosci.*, 14, 1061–1072
- [4] Olmos and Kingdom (2004), McGill calibrated color image database: <http://tabby.vision.mcgill.ca/>

Increments and Decrements in Color Constancy: A Comparison of Natural and Artificial Illuminants

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For color constancy performance, a distinction between incremental and decremental stimuli has proven to be useful [1]. In previous experiments using complex scenes we found systematic variations of increment-decrement processing differences with the color temperature of daylight illuminants [2]. In the present study, our main goal was to compare the strength of these increment-decrement asymmetries for daylights and artificial illuminants not being drawn from the CIE daylight locus. In the experiment, simulations of surfaces and illuminants were presented on a CRT monitor. The stimuli consisted of 5x5 arrays of matte surfaces, which were rendered under one of nine spatially uniform illuminations. Eight different chromatic illuminants and D65 were used. The chromaticities of the chromatic illuminants were chosen from a circle in color space around D65. Two of the simulated illuminants were daylights that appeared blue and yellow to the observer. The remaining six illuminants were artificial lights that appeared red, green, orange, bluish green, yellowish green and pink to the observer. The illuminants were chosen so that the chromaticities of opponent illuminants lay on an axis through D65 in color space. The subject's task was to find an achromatic adjustment for the central square, i.e. to set it so that it looked neither reddish nor greenish and neither bluish nor yellowish. Increments and decrements were defined in relation to the average light signal emitted by the remaining surfaces. Subjects carried out adjustments for five incremental and five decremental stimuli, with luminances between 5 and 40 cd/m. For all subjects we found asymmetries in increment versus decrement processing. In principle, the magnitude of increment-decrement asymmetries varied systematically with illuminant color. The results show two main patterns. First, the increment-decrement asymmetry was strongest for the yellow illuminant. Second, the differences in the strength of this asymmetry were larger for the two chromatic daylights than for any other pair of opponent illuminants. These results could lead to the assumption that the visual system uses information from the strength of asymmetry to estimate the current illumination. Given this conclusion, the cue 'strength of asymmetry' might be more useful for daylight changes than for unnatural illuminant changes.

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[2] Heier, K. & Schultz, S. (2005): Proceedings of the 8th TWK

A Retinal Phenomenon Occurring while Viewing a Light Spot

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We investigate a phenomenon which we suppose to be caused by retinal processing. It occurs when viewing a light spot in an otherwise dark environment. Independently of the color of the light spot, blue arcs get visible to the left and to the right of the spot. There are two such arcs visible with each eye, extending outwards as an upper and a lower arc, with these two arcs circumscribing an area reminiscent of the shape of an almond. The effect is best visible with a bright, red light spot like that of an LED. This phenomenon seems not to have been described beforehand. Therefore, this study aims at describing as carefully as possible the phenomenological side of this effect, including the conditions of its occurrence, its incidence, and a match of the form of these arcs.

An Interactive Simulation of a Parvocellular Retinal Ganglion Cell

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Parvocellular retinal ganglion cells (parvo RGCs), also known as midget RGCs, are the most frequently occurring ganglion cells in the retina: about 80% of all ganglion cells are parvo RGCs. The response of these cells depends primarily on the spatial frequency of the input stimulus. This response is fundamentally different for chromatic and luminance gratings: On luminance gratings the cells strengthen the contrast and thus react like a bandpass filter. On chromatic gratings they give the strongest response to diffuse light and thus they react like a low pass filter. The goal of the present study was to build an interactive stimulation that models the different response properties of parvo RGCs to chromatic and luminance gratings.

The model simulates an on-center off-surround (L+M-) parvo RGC from the fovea. The receptive field (RF) of the cell was realized by a linear DoG as well as a nonlinear shunting model. The model was implemented as an interactive window program in Matlab (The Mathworks). The user can vary parameters of the input stimulus (spatial frequency, contrast, luminance, chromaticity) and of the model neuron (size of center and surround of the RF, surround weight, ratio of L- and M-cones in the surround) and simultaneously view the responses of the model cell.

Interactive exploration of model parameters reveal several basic findings. It is not necessary to have only one kind of cones in the surround: The relative proportion of L cones in the surround can increase from 0% to about 50% without changing the general response pattern of the cell to luminance and chromatic input. Saturation of cells responses can only be modeled based on the shunting interaction which seems to be better suitably for modelling of a visual neuron. The Matlab implementation of the model can be downloaded from <http://www.allpsych.uni-giessen.de/hansen/>.

We have developed a basic interactive simulation that successfully models the responses of a parvo RCG. The simulation program is intended as a teaching program for undergraduate students as well as providing the platform for further scientific studies.

How Color Induction Depends on Hue Differences Between Stimulus and Surround

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Most studies of color induction investigate induction effects around the achromatic point or other equilibrium points. Little is known generally about how the hue of a stimulus is influenced by the hue of an inducing background. Hue can be expressed as azimuth angle in cone-opponent color space. We measured changes in hue angle induced by a chromatic background, using asymmetric matching of 2-degree chromatic patches across different isoluminant backgrounds. One background was neutral gray, the other had a chromaticity corresponding to one of eight hue angles with fixed cone contrast with respect to the gray background. Subjects adjusted the hue angle of the match patch on the neutral background to match it to the test patch on the chromatic background. When plotted as a function of hue angle difference between test patch and background, induced hue angle changes showed a maximum around 41 ± 4 degrees, with maximal induced changes of 24 ± 3 degrees of hue angle. Qualitatively, the curves for different background chromaticities were similar, but the amount of induced hue change depended on the hue angle of the background, indicating that induction is weaker along the S-cone axis than along the M-L axis. The dependence on angular difference is qualitatively similar to the well-known tilt effect, where shifts in perceived angle of oriented stimuli are induced by surrounding orientations. This suggests similar mechanisms of contextual processing for quite different features such as orientation and color.

The Contribution of Color to Recognition Performance in the Non-Human Primate

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Although objects can be identified based solely on the information provided by the spatial structure of an image, color adds another perceptual dimension which may facilitate object identification. Here, we ask whether color in natural images is associated with improvements in object recognition performance. We used a procedure based on Fourier analysis to systematically degrade colored and achromatic natural images. Both stimulus types were mixed with increasing amounts of achromatic noise, leading to loss of spatial structure in the images. At a given noise level, the difference between colored and achromatic images was thus provided only by the remaining color. We used a delayed matching to sample paradigm, where a sample stimulus was presented (250ms), followed by a probe stimulus after a delay period (1s). Sample stimuli were presented at various noise levels, whereas probe stimuli were always undegraded. A lever press was required if the sample stimulus matched or was a degraded version of the probe stimulus. We have preliminary results from one monkey. The monkey's recognition performance decreased as a function of noise level for both color and achromatic conditions. In addition, we found that the recognition performance was significantly higher for the color condition than the achromatic condition at the same degradation level ($p=0.0303$, $N=5$). Since the spatial information for both stimulus versions is equally degraded by the visual noise, these results suggest that color, independently of spatial composition, is associated with an advantage in object identification performance.

Color Constancy for Natural Objects Using Polar Chromatic Adjustment

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Recently, we studied the effect of memory colors on color constancy with photographs of natural objects [1]. When observers made an achromatic setting of various fruit images, the fruits were perceived as gray when the mean color was shifted in a direction opposite to the memory color for each fruit. In those experiments, fruit color was adjusted by a cartesian shift of the chromatic distributions in the isoluminant plane of DKL color space. Because the shape of the distribution was not manipulated, there was residual chromaticity in the stimulus even when the mean of the distribution was at the gray point. Here we investigate the memory color effect using a new polar adjustment method, which enables the manipulation of both the location and shape of the chromatic distribution, and results in a pure luminance variation at the gray point. We presented subjects with digitised photographs of natural fruit and vegetable objects on a CRT monitor with a gray background. The monitor was embedded in a large neutral surround whose chromaticity and luminance were carefully matched to those of the monitor. Subjects adjusted the color of the photographs in the isoluminant plane of DKL color space until the isolated objects appeared either neutral gray or typically colored. The adjustments were achieved by rotating and scaling the chromatic distribution relative to the gray point based on subjects' settings. Although this method enabled setting the object color to a homogeneous gray, achromatic objects were still generally perceived in a direction towards their typical color. For an object to appear achromatic, subjects adjusted the color by ca. 10%-20% in the color direction opposite to the typical setting for that fruit. For example, the banana was adjusted to a bluish color to achieve an achromatic appearance. Our results indicate that the influence of memory color on color constancy with natural objects is a robust effect that does not depend on the way the chromatic distribution is manipulated, and is not an artefact of residual chromaticity in the stimulus.

[1] Gegenfurtner, K. R., Walter, S. & Hansen, T. (2005): TWK 2005.

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Color Constancy and Hue Scaling

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Color constancy refers to the phenomenon of stable color appearance of surfaces with changing illumination. In the present study we used a hue scaling technique [1] to examine the color constancy performance of five subjects in simulated 3D-scenes. In three experiments subjects were asked to judge how blue, yellow, red and/or green a test surface appeared to them on four respective scales ranging from 0 (none) to 6 (very saturated). In the first experiment, simulations of 3D-scenes consisting of various objects were presented to the subjects. The test surface was located at the center of the scene. We used 16 different test surfaces of constant Munsell value and chroma. The scene was presented under a simulated illumination. Five different illuminations were used that appeared achromatic, blue, yellow, red and green to the observer. All stimuli of one illumination condition were presented as a block to control the adaptational state of the subject. Two further control experiments were conducted, in which the test surface was shown in front of a black background. In the first control, the test surfaces that belonged to one illumination condition were presented blocked. In the second control, test surfaces from all illumination conditions were shown in random order. In the 3D-experiment, subjects showed stable hue scalings for a given test surface with changes of the illuminant. Subjects showed good color constancy under all illumination conditions. Surprisingly, the scalings of the subjects in the blocked control experiment were not determined by the color codes of the test surface. Rather they depended on the sequence of previously presented test stimuli. In contrast, the hue scalings in the fully randomized control were completely determined by the color codes of the test surface. We draw three main conclusions from our results. First, our experiments show that hue scaling could be a useful technique to investigate color constancy in a more phenomenological sense. Second, the results from the blocked control experiment underline the important role of chromatic adaptation for color constancy. Furthermore, our results argue for a combination of different cues and mechanisms that underlie color constancy [2].

[1] De Valois, R.L. et al. (1997): *Vis. Res.* 37, 885–897

[2] Maloney, L. T. (2002): *Journal of Vision* 2(6), 493–504

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Visual Perception: Eye Movements

Temporal Contrast Sensitivity During Smooth Pursuit Eye Movements

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During smooth pursuit eye movements, stimuli other than the pursuit target move across the retina, and this might have an effect on their detectability. We investigated whether the detection of such peripheral stimuli is determined by their retinal spatiotemporal frequency content.

We used a 2AFC paradigm to measure detection thresholds for briefly presented (250 ms), 1 cpd, vertically oriented Gabor stimuli of temporal frequencies between 1 deg/s and 24 deg/s, which moved horizontally within a stationary Gaussian window. Observers kept fixation on a small target spot that was either stationary (the fixation condition) at the centre of the screen, or moved horizontally at a speed of 8 deg/s from left to right (the pursuit condition). The motion of the Gabor was either in pursuit direction or opposite to it. This way, a Gabor stimulus with a temporal frequency of 8 Hz moving in the direction of pursuit would be stationary on the retina. The observer's task was to indicate whether the Gabor target was displayed 4 degree above or below the centre of the screen.

We observed that contrast sensitivity was to a first approximation determined by the retinal spatiotemporal frequency content of the stimulus. The temporal frequency cut-off was shifted from 23 Hz under fixation to 16 Hz when the eye and the Gabor target moved in opposite directions and to 27 Hz when eyes and target moved in the same direction. However, there were marked differences in peak contrast sensitivity between the three conditions. Sensitivity was highest for the fixation condition, reduced by 8% for the condition where eyes and Gabor move in the same directions, and reduced by more than 15% when eyes and Gabor moved in opposite directions.

These sensitivity differences could be due to attentional factors, or due to the temporal jitter created by noisy pursuit eye movements. In a further experiment where the motion of the Gabor was vertical and retinal jitter was therefore excluded, we observed a small difference of 6% between fixation and pursuit conditions. This difference is probably due to the focus of spatial attention on the pursuit target. In a third experiment, the target was stabilized on the retina by moving it along with the pursuit target. Here, we still found significant differences between fixation and motion in the direction of pursuit (7%) and between fixation and motion in the direction opposite to pursuit (15%). These numbers are not significantly different from those observed in the first experiment, which excludes retinal jitter as a major contributor to the sensitivity loss during pursuit.

We conclude that visual sensitivity during smooth pursuit eye movements is largely determined by the retinal spatio-temporal frequency content of the stimulus, but significantly affected both by spatial attention on the pursuit target and feature selective attention to motion in the direction of pursuit.

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Saccades Alter Appearance

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Attention can enhance contrast sensitivity at cued locations with the eyes being still. Carrasco et al. [1] could demonstrate that, during fixation, a cue shown briefly before a test stimulus would modify the stimulus' perceived contrast effectively. The aim of our study was to compare the influences of attention and intention on contrast appearance. Human subjects participated in two sets of psychophysical experiments. Subjects sat in front of a computer screen, where visual stimuli were presented. Subjects' head movements were restrained by a chin rest while eye movements were sampled at 500 Hz (EyeLink II, SR Research Inc.). In all cases, subjects had to perform a visually guided saccade task. In a first set of experiments, a first visual stimulus (Gabor patch with one of ten different contrast levels) was presented during stable fixation close to the fixation point. A second stimulus was presented briefly before, during or after an upcoming saccade at the same retinal location with respect to the new fixation location. Using a "two alternative forced choice" task (2AFC), subjects had to decide which stimulus was perceived as having a higher contrast. This task allowed for determining a measure of the time dependent perception of contrast. In a second set of experiments the two Gabor patches were shown simultaneously at identical locations with respect to the old and the new fixation location briefly before, during or after the saccade. Long before the saccade the apparent stimulus contrast was boosted at the point of the presaccadic fixation and was decreased at the target site. This relationship inverted during the execution of a saccade and remained stable, so that after saccade completion the apparent contrast was higher at the target site. This differential effect of spatial location on apparent contrast during saccades was strongly enhanced when the two stimuli were shown simultaneously. In addition, just after completing the saccade an additional postsaccadic enhancement of apparent stimulus contrast was observable. Our experiments consistently demonstrate that the intention to perform a saccade increases apparent stimulus contrast at the target site, as does spatial attention at cued locations. We conclude that the neural processes for spatial perception during attentional shifts and saccadic eye movements are closely related to each other.

[1] Carrasco M, Ling S, Read S. Attention alters appearance. *Nat Neurosci.* 2004 Mar;7(3):308–13

A Replication of Yarbus's Study in Dynamic Scenes

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Eye movements and attention shifts are very closely linked. People continually look at visual scenes with different interests, think of different task goals and modify the pattern of eye movements. Yarbus's study in 1967 revealed how oculomotor behaviour changes depending on different tasks. Subjects were asked to view Repin's painting "unexpected return" and simply answer questions like "What had the family been doing before the arrival of the unexpected visitor?" or "How long has the unexpected visitor been away?" The pattern of eye movements varied with different instructions. In our experiment, we replicated Yarbus' study in a dynamic scene using desktop virtual reality. Twenty subjects participated in this experiment. Their eye movements were monitored with a head-mounted eyetracker as they moved along a fixed route in a virtual environment. Subjects were asked to either estimate the length of the route or to evaluate the quality of the computer graphic application. The sequence of given instructions were controlled. Results showed that eye movement patterns were clearly task-dependent. Subjects directed their gaze on the focus of expansion when they were asked to estimate the length of the route. Only 26% of fixations were on objects in the environment. In order to evaluate the computer graphic quality in the experiment, subjects needed to gaze their attention on visual features of the environment. Subjects increasingly directed their gaze on objects in the environment. Fixations on objects had significantly longer duration and the ratio of fixations on objects in the environment went up to 40%. Previously, we showed that landmarks had longer fixation duration than distractors in a navigation experiment, which reflects the spatial function of landmarks in the navigation task. However, in this non-navigation experiment, we found no difference of fixation duration on objects (landmarks & distractors) in the same environment. Therefore, the difference of fixation duration on landmarks and distractors was specific for the navigation task.

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Gains in Time for using Head-Up Display: A Study of Vergence Changes

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The time period in which the driver looks away from road to check the speedometer is considered to pose an accident risk. In order to reduce this time period, information related to the driving status such as speed, can be presented in the driver's field of view. This is possible by using Head-Up Displays (HUDs). HUD-manufacturers claim that information presented in the HUD is obtained at least 500 ms faster than from conventional displays. The aim of our study was to investigate whether these claims can be confirmed in controlled investigations in the lab. Three computer screens were placed at varying distances to simulate conventional displays (0.6 m), HUDs (2 m) and the traffic environment (10 m). Participants (N = 14) were tested in two sessions on consecutive days. An adaptive nonius measurement was used to estimate the time for changing vergence from 10 m to either 0.6 m or 2 m. The results of our experiment suggest that the mean time difference in perceiving information from conventional display positions and HUD is 106 ms. Possible reasons for the discrepancies of the HUD-manufacturers claims descriptions and our findings are discussed.

Localization of Auditory Targets During Optokinetic Nystagmus

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Previous studies have shown that the perceived location of visual stimuli that are briefly flashed during pursuit or saccadic eye movements is not veridical. In one of our own previous studies we could demonstrate that such a mislocalization is also observed for visual stimuli briefly flashed during Optokinetic nystagmus (OKN), a reflexive eye movement with alternating slow (pursuit-like) and fast (saccade-like) phases. Mislocalizations as found around the time of the fast-phases were similar to those found for voluntary saccades. In our current study we investigated whether such a mislocalization generalizes across senses, i.e. whether it can also be observed for brief auditory stimuli presented during OKN. Experiments were carried out in a lightproof sound attenuated chamber. Normal human subjects performed OKN eye movements elicited by a random dot pattern moving horizontally to the left or right at $10^\circ/\text{sec}$ on a computer screen. During OKN performance an auditory target (white noise) was presented for 5 ms at one of five possible locations. After stimulus offset a ruler appeared on the screen and the subjects had to indicate the perceived target position relative to this ruler. Eye movements were recorded with an infrared recording system (EyeLink2) running at 500 Hz. OKN performance significantly affected the localization of auditory targets in all subjects. The perceived position was shifted into the direction of the slow eye movement. Mislocalization was larger during look- as compared to stare-nystagmus. Hence, our data clearly indicate that spatial mislocalization also occurs (i) during reflexive eye movements and (ii) for auditory targets. However, the two different forms of nystagmus (look vs. stare) differently modulated spatial perception of auditory targets. The observed pattern of these mislocalizations was different from that found for visual targets. This suggests that different neural mechanisms are at play to integrate oculomotor signals and information on the spatial location of visual as opposed to auditory stimuli.

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Visual Contextual Effects on Smooth Pursuit Eye Movements

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We study the spatio-temporal properties of motion signals for the initiation and maintenance of smooth pursuit eye movements in the presence of a visual context. Stationary and moving textured backgrounds have been shown to reduce initial velocity and steady-state gain of smooth pursuit eye movements (e.g., Kimmig, Schwarz, & Miles, 1992). We recorded eye movements from human observers to a small bright Gaussian dot that moved horizontally at 12 deg/s. The visual context in the vicinity consisted of two vertical sinusoidal gratings, one above and one below the stimulus trajectory that were either stationary or moved at the same speed as the target, into the same or opposite direction. We observed that during initiation, eye velocity was increased/decreased by up to 50% when the visual context moved into the same/opposite direction as the target. The effect was persistent but smaller (25% velocity change) throughout the steady-state tracking phase. In a second experiment, the moving context changed speed to 0, 6, or 18 deg/s during the steady-state phase and remained stationary, slower, or faster until the end of the trial. This perturbation only had an effect on steady-state eye velocity when the gratings moved along with the target. At about 70 ms after perturbation, eye velocity increased/decreased by about 20% for an increase/decrease in contextual velocity. We conclude that a visual context flanking the stimulus trajectory can produce the same effect on pursuit performance than a full-field textured background.

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Changes in Eye-Hand Coordination During Rapid Pointing Movements under Risk

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We investigated how eye and hand movements are coordinated during the execution of a goal-directed hand movement under risk. We asked if observers are able to control the relative position of their eyes and hand in a rapid pointing task under risk and whether they can make use of different types of feedback in order to change their eye-hand coordination. In three experiments, we varied feedback about the relative position of the endpoint of the hand and the landing position of the first saccade. Observers were asked to point rapidly to a visually specified target region while trying to avoid a nearby penalty region. Both regions were Gaussian blobs (width=0.5°, contrast 9% (target) and 17% (penalty) respectively), presented within a region 2–4° or 8–10° eccentric to initial fixation. Observers were awarded points (100) if they hit inside the target region, and lost points (0 to –500) if they hit inside the penalty region. In experiment 1, feedback was provided only for the finger landing position. In experiments 2 and 3, additional feedback was provided about the relative distance between the end point of the first saccade and the finger position. In experiment 2, subjects received a penalty if their first saccades landed beyond a distance of 1.5° from the finger end point. In experiment 3, subjects received a penalty if their first saccade landed within a distance of 1.5° relative to the finger end point. Observers were able to alter their performance in order to maximize their gain. Experimental data were compared to a new mathematical model that defines optimal sensori-motor behavior in experiments under these conditions. Optimality was computed based on subjects' motor and saccadic end point variability, similar to optimal performance as defined for rapid pointing under risk [1]. In experiment 2, our model suggests an identical end point for the first saccade and the hand in order to maximize expected gain. In experiment 3, optimal eye-hand coordination implies avoiding the penalty with the finger and simultaneously shifting the first saccade away from the visual target. Our experiments indicate that subjects are able to apply optimal strategies in experiment 2, but fail to do so for experiment 3.

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Eye Movements in Shape Categorization

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The objects that we observe in daily life are not generated by random processes. In general objects inherit their appearance from some coherent generative procedure (e.g., they result from biological growth or they are manufactured for a particular purpose etc.). Consequently, different objects are physically and functionally related to one another. Humans use concepts to represent the relationship between different objects, in order to recognize and categorize them, and to make categorical inferences (i.e. predict properties that are not directly observable but which can be inferred from experience with objects of a certain class).

Depending on the subordinate categorization [1] task and context some features of objects are more diagnostic than others. Most models of categorization silently assume that all relevant features of an object are represented before a category decision is made, and include attentional weights for the different dimensions. We hypothesize that humans selectively sample the observable features in the order of subjective informativeness (esp. cue diagnosticity and availability [2]) in order to make a fast and accurate decision. This would imply that objects don't need to be represented completely and that categorization happens during perception. By tracking the sampling process we could learn more about the informativeness of features in a given context and task.

The task was to learn to categorize novel stimuli into classes forming partially overlapping clusters in a common feature space. Stimuli were generated from (probabilistic) generative models of piecewise NURBS curves forming the closed contours of novel 2D shapes. The curvatures at certain sufficiently distant control points were used as the features in which the classes differ. The other control points were kept the same for all stimuli. The classes specified multi-dimensional Gaussian distributions in this feature space. The overlap of the distributions along each dimension therefore determined its diagnosticity. On each trial feedback was given whether the correct class was selected. As the task cannot be solved perfectly by definition, the experiment was terminated when the learning curve showed no more significant improvements. Subjects were instructed to make as fast and as accurate decisions as possible. Eye movements as a form of overt attention were recorded to track the feature sampling process.

We discuss the results of ongoing experiments, esp. under which circumstances and how well humans can learn to solve this task, and how the target locations and sequence of eye movements are related to their performance. The results are compared to a model of an ideal Bayesian learner sampling the features in an order of maximizing information gain given its current knowledge about the task.

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Saccadic Facilitation with Natural Scene Backgrounds

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Saccades have been traditionally studied using very basic stimuli (e.g., a spot of light on a uniform background). We compared perceptual versus saccadic performance within a semi-naturalistic context: A Gabor target at one of several spatio-temporal frequencies was embedded in either a stationary background texture known to have similar statistical properties as natural images (i.e., pink noise), or on a uniform gray background. Observers made a saccade to the target presented left or right of fixation at an eccentricity of 8 deg. Target contrast was varied. After each trial, observers made a 2AFC as to the target's location (left versus right). We compared psychometric functions for targets on each background, and then examined saccade latency at points of equal detection performance. At a given level of equal detection performance, latencies were often reduced by as much as 80 ms for targets appearing in the structured background. Furthermore, the pattern was very similar with images of natural scenes as backgrounds. The results support the idea that natural contexts can facilitate a saccadic response.

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Visual Perception: Motion

The Role of Feature Attention in Motion Perception—A Computational Study about the Interplay of Attentional Selection and Mutual Competition

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Problem: Given a specific task or an immediate experience observers often focus their attention on one specific aspect of the visual input. A special form of attention is feature attention where certain features, such as motion direction are attended irrelevant of their spatial location. There is evidence that feature attention modulates neural activity in early visual areas [1]. For motion sensitive cells modulatory effects have been reported in visual areas such as MT or MST [2, 3]. Psychophysical experiments, on the other side, reveal behavioral effects in which attention increases the observers' performance in motion discrimination tasks [2, 4]. It remains largely unclear how results from often different studies relate. **Approach:** In this work we build upon a neural model of cortical motion perception [5] to explain distinct experimental observations within a single theoretical framework. We use our model to link a physiological study of feature attention in cortical motion processing [3] to a psychophysical experiment of motion perception [4]. The model consists of a layered architecture simulating the function of primate areas V1 and MT. Model neurons in each area are coupled via feedforward integration, lateral shunting competition and excitatory feedback modulation. To model feature attention the model dynamics is biased by an excitatory top-down attention signal indicating attended motion features. **Results:** Our results replicate physiological data on feature attention such as the modulatory influence of attention and the suppression of competing non-attended features [3]. The model further generates behavioral data in a decision experiment that is consistent with psychophysical observations [4]. Although [2] argued that attention modulation increases the signal-to-noise ratio our model gives more detailed explanations about different contributions of different neural mechanisms on neural and behavioral effects. Based on our computational simulations we predict a decreased performance in motion detection tasks derived from [4] when the wrong direction of motion is attended. Moreover, the model also successfully processes real-world sequences illustrating the practical use of feature attention to highlight objects of interest in a scene. **Conclusion:** In sum, the model explains experimental findings from behavioral as well as physiological investigations. The key underlying function relates to the biased competition framework by utilizing soft-gating modulatory feedback combined with shunting competition. The ability to process real-world sequences further demonstrate the competency of the proposed model.

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Age-Related Differences in Motion Tasks of Different ComplexityJutta Billino,¹ Frank Bremmer² and Karl R. Gegenfurtner¹¹Justus Liebig University Giessen, ²Philipps University Marburg

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Several studies have shown that motion sensitivity declines with increasing age [1]. This decline cannot be attributed to optical changes but is due to changes in the central visual pathways. However, there is little knowledge which subsystems are prone to degeneration. Whereas research focused mainly on age-related differences in the perception of motion at an early processing stage, only few studies investigated age effects on motion processing at advanced stages in the visual system [2, 3]. The purpose of our study was to evaluate the effect of aging on motion processing at different stages in the visual system. We chose the detection of coherent motion as a task processed at an early stage and contrasted it with the detection of two types of complex motion information, namely biological motion and radial flow, which relies on processing at advanced stages. Subjects of three different age groups participated in our study: young subjects (19–38 years; $n=14$), old subjects (61–69 years; $n=21$) and old-old subjects (71–82 years; $n=28$). We controlled for visual acuity and ocular diseases. The first task required subjects to detect which one of two random dot kinematograms displayed at 7.6° eccentricity and a size of 9.6° contained coherent motion. In the second task, subjects had to indicate which kinematogram contained a walker performing biological motion. In the third task, subjects had to decide about the direction of heading of a radial flow large-field stimulation whose focus of expansion was shifted to 5.8° eccentricity. The percentage of signal and noise dots in the kinematograms was varied and thresholds were estimated by fitting the percentage of correct answers with a logistic psychometric function. Thresholds for coherent motion detection differed significantly between the young group and both older groups (15.1% vs. 27.0% vs. 30.0%). There was an overall effect of age on performance ($r=.574$). Regarding biological motion, results revealed a rather weak correlation between performance and age ($r=.264$). The performance difference between the young and the old-old group reached significance, but was small (12.3% vs. 17.3%). The ability to detect radial direction was not affected by age. These results suggest that older observers' ability to detect complex motion information can be preserved despite elevated detection thresholds for coherent motion. This finding puts into question a hierarchical view of visual motion processing and points to different time courses for sensitivity decline regarding coherent motion, biological motion and radial flow.

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Localization of Moving Sound

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The final position of a moving object usually appears to be displaced in the direction of motion. This phenomenon, termed representational momentum, has initially been reported for visual targets [1]. Recently, an analogue of this phenomenon was also observed with moving auditory targets [2,3]. The present study investigated whether the auditory representational momentum is confined to the final position of motion or emerges during motion. For this purpose, the localization of a moving sound was tested at different points in time. In a dark anechoic environment, an acoustic target (noise pulses) moved from left to right or from right to left along the frontal horizontal plane. The velocity was 12 deg/s. In the initial, middle, or final phase of the motion trajectory or at the end of motion (i.e., at the moment the target was at its final position), listeners received a tactile stimulus and determined the current position of the moving target at the moment of tactile stimulation by performing a pointing task. Alternatively, they did not receive a tactile stimulus. In this case, the listeners localized the final position of auditory motion. In the initial phase of auditory motion, the sound position was perceived to be displaced in the direction of motion (3.5°; SE +/-1.4°). This forward displacement decreased in the middle (1.1°; SE +/-1.1°) and final phase of motion (0.4°; SE +/-1.3°). At the end of motion, the forward displacement slightly increased (1.4°; SE +/-1.0°). However, when the motion stimulus had ceased, its final position was substantially shifted in the direction of motion (4.1°; SE +/-1.8°). These results suggest that the representational momentum in spatial hearing is a phenomenon specific to the final point of motion. Extrapolation of past trajectory information could be a potential source of this perceptual displacement. Thus, the auditory system could incorporate future positions of the moving object to compensate for delays within the neural pathway. The effect of motion extrapolation, which subserves the localization of a moving sound, may become evident when the target abruptly disappeared. In this case, the dynamic representation may not stop immediately, but overshoot the final position in the direction of motion.

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Assessment of the Similarity Metrics of Biological Motion Perception

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The perception and categorization of body movements is an important visual function. However, the nature of the underlying perceptual representation is largely unknown. Classical work in psychology has linked the perceived similarities of stimulus classes with differences of their physical properties. This approach has been very successful, e.g. for simple and complex form stimuli. We tried to extend this approach to biological movements. **METHODS:** Classes of biological motion stimuli were generated by motion morphing, by computing linear combinations of prototypical gait patterns. Different sets of stimuli were tested, which formed different geometrical configurations in the linear morphing space. Perceived similarities between these stimuli were assessed within a Pairs-of-Pairs Comparison paradigm. Either single or multiple views of the same actions were presented. Subjects had to ignore the view direction in their similarity judgments. The physical similarity of the movement trajectories was assessed by computing different spatio-temporal distance measures from the 2D dot trajectories, and from the 3D joint trajectories. From the distances, low-dimensional configurations were recovered by multi-dimensional scaling (MDS). Similarities between the recovered configurations were quantified using Procrustes analysis. **RESULTS:** Subjects were able to give similarity judgments that were largely independent of view angle, consistent with the task. For stimuli with the same view angle, good approximations of the perceptual similarity metrics were obtained with a physical metrics that is given by the Euclidean distance between the dot trajectories after time-alignment. For stimulus set with multiple views, a good approximation of the perceptual metrics was given by a two-dimensional embedding of the 3D distances between joints (after time alignment). More than two-dimensional embeddings of recovered configurations did not improve the results. **CONCLUSIONS:** (1) The perception of biological motion seems to reflect the veridical physical distances between motion trajectories. (2) For the approximation of the perceptual metrics, time-alignment of the compared trajectories seems to be important. (3) The 3D distances between the joint trajectories do not account for the observed view-dependence of subject's similarity responses. Rather this result seems compatible with a view-based encoding of biological motion patterns.

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Oculomotor Functions and Self-Motion Perception in the Elderly

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In normal subjects, vision (optic flow) provides most of the relevant information for determining ones direction of self-motion, i.e. ones heading. In our present study we asked whether the capability of using optic flow for heading detection is constantly available throughout life or whether we could find indications for age-related changes.

Psychophysical experiments in normal human subjects were performed in visual virtual reality. Subjects were separated into two experimental groups: one control group of middle-aged subjects (25+/-5 years) and one test group of older subjects (65+/-10 years).

In a first step we examined the case of translational self-motion through a 3D-cloud of random dots. Stimulated observer speed was constant, while presentation time and dot density was varied in blocks of trials. After stimulus presentation a ruler was presented in the visual field and subjects were asked to indicate their perceived self-motion direction by giving the number on this ruler being nearest to the perceived heading. In a second set of experiments we induced a random perturbation to the flow field. Dots randomly disappeared from the screen and appeared at a new position with new movement vectors. Only 50% of these movement vectors were in accordance with the simulated heading direction. In a final set of experiments we examined the role of stereoscopic visual information on heading performance.

Results from the first experimental series showed that heading accuracy for elderly subjects was generally worse than for young observers. Surprisingly, the elderly subjects seemed to be impaired to make use of increasing visual information in the display as provided by longer display durations and larger number of dots in the display. In comparison, the performance of the test groups significantly increased with the increasing visual information. The second set of experiments revealed an influence of the perturbation on heading detection only for shorter presentation times. The decline in performance was most prominent for the control as compared to the test group. The last set of experiments showed an overall improvement of heading detection for stereoscopic stimuli. This improvement was found for test and control groups for longer presentation times and larger number of dots but not for short presentation times and a small number of dots. In summary, our data clearly show that heading detection decreases with age and that it is mostly the lack of making use of increased visual information content that differs between aged and control groups.

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Unsupervised Learning of Perceptual Important Features in Emotional Body Expressions

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Humans are able to communicate emotions through their posture, and through the dynamics of their body movements. Apart from faces, features that convey critical information about specific emotions have only rarely been studied, typically based on perceptual ratings (e.g. Montpare et al., 1987; Meijer, 1991; Wallbott, 1998). A more quantitative characterization of informative features can be obtained by a statistical analysis of trajectories of emotional body movements. Studies on image statistics have shown that Independent Components Analysis (ICA) allows to extract features relevant in the perception of natural images and faces. This motivates the question whether related approaches allow to extract informative spatio-temporal components for the visual perception of emotional body expressions. **METHOD:** Our analysis was based on motion capture data from actors performing actions with different emotional affects. This data was analyzed with existing ICA methods, and with a new algorithm that combines nonlinear ICA with feature extraction by sparse regression. We extracted spatio-temporal components that contributed maximally to the approximations of movements with different emotional styles. In a psychophysical experiment, we tested the relevance of these components for the visual emotion categorization. **RESULTS:** Opposed to standard ICA, the new algorithm extracts a small number of spatio-temporal features that are specific for individual emotions. These seem to correlate with features that are important for the categorization of emotional body expressions in perception experiments. Informative features for visual recognition might thus reflect distinctive components in motor patterns that cannot be extracted with basic algorithms, like PCA or standard ICA.

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Blame the Road Ahead but not the Fog for Speeding

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Optic flow affects the walking speed during human pedal locomotion: when the ground texture is moved in a direction opposite to the walking direction, people slow down despite noticeable changes in their physical effort. We hypothesized that in driving conditions, where no direct matching between physical effort and produced speed exists, the role of the optic flow should be even more pronounced. Similarly, fog is supposed to reduce the perceived driving speed, by a reduction of the contrast of the visual scene. This, subsequently, should lead to a speeding during fog [1]. We aimed to replicate these results using a large field-of-view, a real road trajectory and a realistic exponential fog model. We used a driving simulation which was back-projected on a large fronto-parallel projection screen (75 x 70 degrees). Participants were trained to learn the relation between current driving speed (digital speedometer) and amount of optic flow in the image plane. In the experimental phase, we varied environmental condition (clear vs. foggy scene), speed signal (40, 60, and 90 km/h), and road texture motion. By adding motion to the road texture, the apparent driving speed was increased to 150% or reduced to 67% of the actual driving speed with regard to the rest of the environment. After the beginning of the trial, a speed signal indicated the required speed. The participants were instructed to accelerate up to this speed, keep it for five seconds, and terminate the trial by button press. The average speed of the last five seconds of each trial was included into the analysis. We found a significant effect of the motion of the road texture on the produced driving speed. As expected, participants increased the driving speed when the texture motion indicated a slower speed and vice versa. We observed also a significant fog effect which is in opposition to the previous results: when contrast was attenuated by fog the driving speed was reduced. Our study raises serious doubts about the previous interpretation of the relation among contrast reduction, perceived speed and driving behavior. In a realistic driving scenario, fog does not directly lead to speeding. However, the large effect of texture motion, suggests that the optic flow, especially originating from the road ahead, clearly determines the perception of the driving speed, even in foggy conditions.

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Optimal Integration of Movement Components for the Visual Recognition of Emotional Body Expressions

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The visual recognition of complex shapes is likely based on an integration of simpler components, such as fragments or geons. Analogously, the recognition of complex body movements might be accomplished by an integration of simpler movement components. The existence of motion components is suggested by findings in motor control: complex motor behavior seems to be organized in terms of simpler components, called synergies, which encompass only subsets of the available degrees of freedom (joints). Our experiment tested how the visual system integrates information from components of emotional body movements that were either congruent or incongruent with components recovered from motor execution. If the motor and visual system interact, then recognition performance of the congruent type should be superior to that of the incongruent. **METHOD:** We motion captured lay actors performing a number of body movements expressing different emotions. Spatio-temporal components specific for individual emotions were extracted from the movement trajectories by an algorithm that combines Independent Component Analysis and sparse feature learning. By motion morphing, we generated point-light stimuli with different amounts of emotional style information in different joint combinations. These joint combinations matched, or did not match, the components extracted from the movement trajectories. Subjects had to detect the emotions expressed in these displays. By modeling of the perceptual performance by a Bayesian cue-fusion model, we were able to test whether subjects' perception integrated the information from the components in a statistically optimal way. **RESULTS:** For all tested components, performance was close to an ideal Bayesian integration of information components. This shows that the visual system seems to extract a maximum amount of information from the available components. However, we did not find an indication that components recovered from motor execution are more efficiently integrated than other spatial motion components.

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Phase Lags and Gain Ratios in Motion Perception During Smooth Pursuit Eye Movements

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During everyday viewing we rarely keep our eyes still. Our visual system has to take these eye movements into account in order to create a veridical percept of object motion. When we make smooth pursuit eye movements, the perceived velocity of a moving object can be obtained by summing two signals, one estimating retinal image velocity and the other estimating eye velocity. Previous studies have shown that the gains of these two signals differ. Here we investigate whether they also differ in their latencies. Observers compared the peak velocity of sinusoidally moving dot patterns viewed during sinusoidal smooth pursuit eye movements and during fixation. The relative gains and phases of the two signals were estimated from the amplitude matches by fitting a simple linear model. At VSS2005, we showed that the model described the data well for most observers, but the estimated signal gains and phases showed considerable variability. Also, the gain ratio was very low for most observers, suggesting they ignored eye-velocity information and judged instead the relative motion in the display. Here, we tested whether removing the vertical edges in the stimulus window, using a large-field cylindrical screen, promoted head-centred judgements. Using this display, observers seem more able to judge head-centred sinusoidal motion consistently during smooth eye pursuit. Relative signal gain was comparable to that previously reported in the literature. Moreover, the results suggest that retinal motion signals lag eye-movement signals by a small amount.

Do Rats Use Optical Flow for Motion Control ?

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Animals in motion may control their movements based on different visual stimuli. Under common conditions a subject's egocentric relation towards a visible goal and the information about its self-motion based on optical flow are concordant, which makes it impossible to distinguish how they contribute to navigational control. Recent studies with human subjects used virtual environments where the visual information was manipulated. For example, Warren et al. [1] could show that humans in fact do use the optical flow information for navigational control. I used a virtual reality setup designed for rodents [2] to test if this result also applies to rats. The setup consists of a running ball surrounded by a 360° video screen. In this virtual setup, the subjects first learned to navigate towards visual goals. In experimental trials the rats' movements in the virtual world were shifted by a fixed angle relative to its real-world movements, resulting in an optical flow field with a focus of expansion (FOE) that was shifted from their moving direction. Depending on how visual information is used in course control, different trajectories for the approach to the goal can be predicted. Straight approach lines can only be achieved using optic flow information whereas orientation based on the egocentric relation to the goal alone will effect a curved line. In different experimental conditions, I varied the amount of optic flow information available to the navigating rat. These variations had a clear effect on the rats' trajectories, indicating that optical flow information has an impact on the rats' motion control. However, further experiments are required to ascertain how the rats perceive and process the optical flow information.

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The “Stepwise-Constancy Illusion” (SCI): Constancy Performance of Edge Positions in the Peripheric Visual Field is Accomplished in Visible 70ms Steps

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This novel illusion appears when a field of optical flow made up by patterned tiles is looked at from the corner of one's eyes at an angle between approximately 20° and 51° eccentricity. The illusion is supported by a low-contrast random pattern of the tiles and becomes evident at angle velocities between $1.5^\circ/s$ and $11^\circ/s$. A suitable optical flow can be attained by smoothly moving one's head within 1.5s towards the tiles, starting from a distance of 60cm and progressing to a distance of 30cm, and then moving back again to the initial position. When concentrating on the perceived motion of the joints between the tiles in relation to the optical flow, one can see that vertical, horizontal and diagonal joints seem to jump stepwise in the opposite direction. Although their images on the retina are moving steadily, the joints are perceived as if staying at the same retinal site, yet jerking. Specifically, when the eyes are smoothly approaching the tiles, the area, which is enclosed by the jerking joints seen in the visual periphery, paradoxically shrinks stepwise at about 14 Hz, as determined by equalisation with the flicker of a stroboscope. Accordingly, when the eyes recede from the tiles the area between the jerking joints seems to extend, although it is shrinking in the retinal image. Thus, the perceived images of the jerking joints do not appear on the retina, but if they were there, where they seem to be, they would turn out to be virtually retina-stabile. As two or more successive joints can be seen to move simultaneously in that paradox way, the illusion is produced in a large region of the peripheric visual field and thus cannot be due to a local change of some retinal algorithm. Rather, there seems to be a local plateau as described by H. Strasburger (2003). While the retinal image of the tiles is shrinking, constancy performance makes us perceive that their sizes remain the same. The SCI indicates that in the visual periphery the result of constancy performance is updated every 70 ms only. Time resolution of flicker is higher in the visual periphery than in the center, but time resolution of moving edges is lower. It might be hypothesized that this feature of our visual system improves the well-known sensitivity to moving objects in the peripheric visual field, in spite of its low spatial resolution.

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Visual Perception: Spatial Vision

A Cinematic View of Space. Methodological Reflections on the Research of Spatial Effects

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The dissertation attempts to comprehend architectural space by means of filmic structures of perception. In view of the definition of space perception and spatial effect the view goes beyond the limits of architecture and creates thus a new understanding of what is presumedly known. The film serves as research model because it also creates spatial effects, yet within a different scale and transferred with a different intention.

This transdisciplinary approach aims to disclose conventionalized patterns of perception and by means of a terminological transfer from the film language to enlighten phenomena of the spatial effect in architecture within an intermedial relation.

The investigation studies the space-effective and filmic creative means such as framing, cutting and narrative perspective and transfers those into architecture: The filmic concept of framing which deals with different views of the frame introduces for example the concept of the offscreen into architecture and explains how the imagination of the viewer can be stimulated by deliberately hiding parts of the space. The analysis of the filmic cutting assumes that space perception in architecture is no continuous process but consists of single segments, sections or visual spaces. This idea leads amongst other things to the formulation of the spatial cut, which describes the experience of space, taking into consideration the subject-related visual sensuous understanding. The narrative perspective finally investigates discursive structures and spatial narrative strategies transferring them into the architectural analysis. This demonstrates that for example the choreographic movements similar to the filmic setting generate many-layered space views and thus compress the impression of space.

It can finally be concluded that the quality of space cannot be judged by its abstract and formal design structure, but has to be discussed with regard to the perceiving subject. Thereby the concept of space is split into an outer, measurable, materially existing space on the one hand and on the other hand into an inner recipient-dependant space, which is determined by the personal and cultural character of the viewer. The selected methodology, which applies film as a research model, thus allows from specific situations to perceive that the effect of space is a structure outlined for this space, which subsequently is recognized and understood by the viewer. The concept of actualization permits not to split the idea of the space effect, but to integrate it into a process operating in two phases.

Identification and Perceptual Relevance of Abnormal Visual Field Representations in Human Albinism

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Purpose: In albinism the central part of the temporal retina projects abnormally to the contralateral hemisphere [1]. We used visual evoked potentials (VEPs) to identify the abnormal temporal retina and tested whether the retinal abnormality coincides with selective visual field defects. **Methods:** In 15 patients with albinism VEPs were recorded to determine the horizontal extent of the projection abnormality: Visual stimuli (black-and-white checkerboard patterns; 98% contrast; mean luminance 22 cd/m²) were presented in a randomised order in one of 10 adjacent rectangular apertures along the horizontal meridian (horizontal extent in left or right hemifield: 0–2,5; 2,5–6; 6–11,5; 11,5–17; 17–27°; vertical extent: ±12°). VEPs were recorded from occipital electrodes (O1–4) referenced to Fz during monocular stimulation of each eye. The differences of the VEPs recorded over opposing hemispheres were calculated to assess the lateralisation of the responses [2]. The difference traces obtained for each eye were correlated with each other, which allows the differentiation between a normal and an abnormal projection of the optic nerves: Positively correlated traces indicate that both eyes project to the same cortical regions, while negatively correlated traces indicate that both eyes project to opposing hemispheres. In the same 15 subjects with albinism standard static white on white perimetry was used to measure light spot detection thresholds (Octopus 101). **Results:** In each of the 15 patients with albinism VEP responses indicated an abnormal projection of the para-central temporal retina, while they indicated a normal projection of the peripheral temporal retina. Depending on the subject between 2 and 15° of the central temporal retina projected abnormally (median 8°). No selective visual field defects were evident for the abnormally projecting part of the retina. **Conclusion:** The projection abnormality, which results in an abnormal cortical representation of the temporal retina, does not selectively suppress visual performance in a light spot detection task. It is concluded that cortical self-organisation makes the abnormal representation available for visual processing. It remains to be investigated whether this also applies to higher order visual tasks, i.e., pattern- or motion-detection.

[1] Hoffmann et al. (2003) *J Neurosci* 23:8921–8930

[2] Apkarian et al. (1983) *Electroenceph Clin Neurophysiol* 55:513–531

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Perisaccadic Mislocalization of Visual Targets: From Shift to Compression

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It is now well established that for a brief period around the time of a saccade the perception of space is disturbed. Brief visual stimuli that are presented perisaccadically are perceptually mislocalized. Depending on the presence of postsaccadic visual references, the mislocalization patterns differ in magnitude and shape [1,2,3]. Stimuli presented at any location in otherwise total darkness are subject to a uniform translation along the direction of the saccade. Before saccade onset the perceived locations are shifted in the direction of the saccade, after the end of the saccade the perceptual shift points in the opposite direction. In lighted surroundings a bidirectional mislocalization pattern centered around the endpoint of the saccade is observed. All perceived stimulus locations are attracted by the landing point of the eye resembling a compression of space. While the trigger of the change in mislocalization patterns seems to be identified by postsaccadic visual references, its underlying mechanisms remain unclear. Accordingly the goal of our present study was to further elaborate the role of the illumination level and of visual references for spatial localization during saccades.

We asked human subjects to localize brief visual stimuli that were presented during a visually guided saccade task. In a blocked design we modified visual references by varying the structure of the monitor's background and the illumination level of the surroundings. The results were analyzed by calculating a shift- and a compression index as proposed by Lappe et al. [2] and by determining the peak values and their corresponding times from the mislocalization patterns.

Our results show a gradual transition from shift to compression for increasing background and illumination levels. The presaccadic shift in saccade direction for stimuli beyond the saccade goal decreases whereas the postsaccadic mislocalization against the direction of the saccade reverses its direction. This behavior can be explained by a decreasing shift component that gets replaced by an increasing compression component rather than by a pure additive superposition of both effects. Surprisingly we observed increasing compression levels in trials that did not differ in the amount of given visual references but rather were conducted at higher luminance levels. This might indicate that besides the presence of visual references the illumination level might also be a crucial parameter for the particular mislocalization pattern.

[1] Cai et al. (1997): Nature 386, 601–604

[2] Lappe, M. et al. (2000): Nature 403, 892–895

[3] Ross et al. (1997): Nature 386, 598–601

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Size Illusions Caused by Border Lines—Does Blurring Play a Dominant Role?

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There is a group of visual illusions which give the impression that straight border lines of a rectangle are bent or that rectangles look wedge shaped [1]. In a simple form, it may be described in the following way: On a white surface area, e.g., an upright rectangle is surrounded by a black border line. At half height, the interior of the rectangle is black, while on moving towards the bottom and the upper end, the black gradually turns into grey and finally fades away into white. When the width of the contour line is chosen such that it approaches the resolution limit of the eye, the rectangle seems to change its shape, giving the impression of being wider at the top and the bottom and narrower in between.

We have investigated this illusion experimentally on 10 different examples of this illusion. The result is given in a table, together with the illusions.

Possible explanations are discussed: 1. Blurring of the border line. This effect was discussed for other types of illusions [2]. We have performed calculations in order to check to which amount this may contribute to the illusions in our case.

2. Visibility of the borderline depending on the hue of the adjacent areas.

3. Variation of the conspicuity range due to the existence of fine structural details. This hypothesis was discussed already in connection with the moon illusion [3]. Examples are presented which seem to support this hypothesis for this type of illusion as well.

4. The irradiation illusion [4].

The arrangement of several areas, of the same shape and a particular type of shadowing, next to each other can lead to a variety of illusions, some of them reminiscent to the Muensterberg illusion. In some cases flickering is observed. Examples of illusions produced by colouring are also presented.

[1] Kreiner, W.A. (2005); Proc. of the 8th Tübingen Perception Conference

[2] Fermüller, C. and Malm, H. (2004); Vision Research 44, 727–749

[3] Kreiner, W.A. (2004); Z. Phys. Chem. 218, 1041–1061

[4] von Helmholtz, H. (1867); Handbuch der Physiologischen Optik. Voss (Leipzig)

The Visual System's Representation of Natural Images

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Previous studies (Atick and Redlich, Field, Webster and Miyahara) have investigated how the visual system could optimally represent the $1/f$ amplitude spectrum of natural images. Computational studies (Atick and Redlich, Field) suggest that the cortical representation ought to be a “whitened” version of the amplitude spectrum of natural images, i.e. spatial frequencies are equally represented despite the abundance of low spatial frequencies and dearth of high spatial frequencies in photographs of real world scenes. Webster and Miyahara showed that adaptation to natural images attenuates sensitivity to low spatial frequencies effectively supporting the computational evidence. We attempt to measure to what degree different spatial frequencies contribute to the percept of an image, in order to determine the extent of whitening of the input. To do this we adapted subjects briefly (250ms) to textures (4×4 degrees) of different spatial frequencies (1, 2, 4, 8, 16 cycles/degree, bandwidth 1.4 octaves—full width at half maximum). Then we measured the perceived contrast of $1/f$ textures in the adapted region of the visual field using the following procedure: After each interval of adaptation subjects judged whether the texture in the adapted region had a higher or lower contrast than that of the same texture in a non-adapted region. The contrast of the comparator texture (non-adapted) was changed after each time the subject made a judgement according to a 1 up 1 down staircase. We found that attenuation of perceived contrast, due to adaptation, is greatest when the adapting frequencies are at the peak of the contrast sensitivity function. It seems there is some “whitening”; however this is, at best, incomplete.

[1] Atick, J.J. & Redlich, N.N., (1992), *Neural Computation*, 4, 196

[2] Field, D.J., (1987), *J. Opt. Soc. Am.*, 4, 2379

[3] Webster, M.A. Miyahara, E., (1997), *J. Opt. Soc. Am.*, 14, 2355

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Localising Moving Stimuli with a Pointing Task and a Relative Judgment Task

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It is long known that observers make localization errors in the direction of motion when asked to point to the perceived onset position of a moving target (Fröhlich effect). However, recent studies revealed a strong effect of trial context: When the stimuli did not appear at predictable positions but at unpredictable positions, pointing errors in direction of motion were at least drastically reduced (Müsseler & Kerzel, *VisRes*, 2004). In the present experiments this effect of trial context was examined with an absolute pointing task and a relative judgment task. The first experiments indicated that the trial context had a strong impact on the observers' judgments in the pointing task, but not on the relative judgment task. However, when observers were informed about the task only after stimulus presentation, the effect of trial context was also observed with the relative judgment task. Thus, the task had a strong impact on perceived spatial positions.

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The Pedestal Effect is Caused by Off-Frequency Looking, not Nonlinear Transduction or Contrast Gain-ControlFelix A. Wichmann¹ and G. Bruce Henning²¹MPI for Biological Cybernetics, Tübingen, ²Oxford University

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The pedestal or dipper effect is the large improvement in the detectability of a sinusoidal grating observed when the signal is added to a pedestal or masking grating having the signal's spatial frequency, orientation, and phase. The effect is largest with pedestal contrasts just above the 'threshold' in the absence of a pedestal. We measured the pedestal effect in both broadband and notched masking noise—noise from which a 1.5-octave band centered on the signal and pedestal frequency had been removed. The pedestal effect persists in broadband noise, but almost disappears with notched noise. The spatial-frequency components of the notched noise that lie above and below the spatial frequency of the signal and pedestal prevent the use of information about changes in contrast carried in channels tuned to spatial frequencies that are very much different from that of the signal and pedestal. We conclude that the pedestal effect in the absence of notched noise results principally from the use of information derived from channels with peak sensitivities at spatial frequencies that are different from that of the signal and pedestal. Thus the pedestal or dipper effect is not a characteristic of individual spatial-frequency tuned channels.

Index of Authors

- Aglioti, S. M., 37
Agotai, D., 168
Altmann, C., 120
Andersen, O. K., 108
Angelaki, D., 20
Arendt-Nielsen, L., 108
- Barth, E., 91
Bartz, D., 119
Bausenhardt, K. M., 48
Bayerl, P., 123, 156
Bethge, M., 90
Beykirch, K., 22
Biber, P., 66, 67
Biber, U., 82
Billino, J., 157
Bles, W., 25
Böhme, M., 91
Bompas, A., 132
Bos, J., 25
Bratzke, D., 49
Braun, C., 109
Braun, D. I., 146
Bremmer, F., 147, 150, 157, 160, 170
Bülthoff, H. H., 22, 74, 79, 118, 119, 121, 127
Bülthoff, I., 72
Burda, H., 31
Busch, F., 67
Butler, J., 22
- Chatziastros, A., 162
Christen, V., 76
Chuang, L., 118
Colonus, H., 73, 75
Conrad, V., 50
Cooke, T., 74
Cunningham, D., 119
- Dehnhardt, G., 30
Delipetkos, 146
- Denzinger, A., 45
Diederich, A., 73, 75
Dörre, C., 133
Dörschner, K., 143
Dominy, N., 29
Dorr, M., 91
Drewes, J., 92
Drewing, K., 76
- Edelman, S., 159
Ehbauer, N., 126
Ernst, M. O., 77–79, 87
- Fernandez, R., 86
Fischer, J., 119
Fleck, S., 66, 67
Fleming, R. W., 93
Frank, A., 100
Franz, V. H., 84
Freeman, T. C. A., 164
Frensch, P. A., 40
Freyberg, S., 83
Frissen, I., 77
- Garsoffky, B., 112, 114
Gegenfurtner, K. R., 91, 92, 134–136, 139, 142, 146, 151, 154, 157
Gerstmayr, L., 94
Getzmann, S., 158
Giese, M. A., 159, 161, 163
Giesel, M., 134
Gillner, S., 113, 148
Glasauer, S., 21
Gong, W., 24
Groen, E., 25
Grosjean, M., 51, 52, 88
- Haberland, U., 147
Haburcakova, C., 24
Haggard, P., 37
Hamburger, K., 135

- Hansen, T., 134–136, 139, 142
 Hardiess, G., 113
 Hecht, H., 23
 Heier, K., 137
 Helbig, H., 78
 Henning, G. B., 174
 Hesse, C., 84
 Himmelbach, M., 105
 Hodzic, A., 104
 Hölzl, R., 108
 Hoffmann, M., 169
 Hofmann, P., 53
 Huberle, E., 120
 Hübner, W., 68, 80
 Huff, M., 112, 114

 Ilg, U. J., 82, 83, 85

 Jäkel, F., 74
 Jaschinski, W., 149
 Jentzsch, I., 86
 Jin, Y., 148
 Jovanovic, B., 76

 Kaernbach, C., 133, 138
 Kaim, L., 139
 Karnath, H.-O., 105, 120
 Kayser, C., 28
 Kerzel, D., 154
 Kiko, S., 100
 Kirschfeld, K., 96
 Klauke, S., 140
 Kleinböhl, D., 108
 Klingenhoefer, S., 170
 Knauff, M., 127
 König, M., 149
 Königs, K., 150
 Koselj, K., 44
 Kourtzi, Z., 50
 Krägeloh-Mann, I., 101
 Kreiner, W. A., 171
 Krüger, S., 60
 Kunde, W., 38

 Lange, C., 79
 Lehmann, M., 128
 Lennert, T., 61
 Leuthold, H., 86
 Lewald, J., 158

 Lewis, R. F., 24
 Lich, M., 160
 Liebe, S., 141
 Logothetis, N. K., 141
 Long, D., 97, 122
 Lukas, J., 60
 Lutzenberger, W., 61, 101

 Ma-Wyatt, A., 152
 Mallot, H. A., 68, 80, 94, 113, 126, 129, 148
 Maloney, L. T., 143
 Mancini, B., 37
 Mandler, A., 85
 Martinetz, T., 91
 McDonald, J. S., 172
 Meilinger, T., 127
 Melcn, M., 45
 Merfeld, D., 24
 Mertens, L., 109
 Miller, J., 63
 Morrissey, J., 24
 Muckli, L., 104
 Müsseler, J., 173

 Nattkemper, D., 40
 Neidhard, E., 128
 Neumann, H., 123, 156
 Newell, F. N., 72, 79
 Nowak, D. A., 36

 Olkkonen, M., 142
 Omlor, L., 161, 163
 Ostwald, D., 109

 Penn, D., 33
 Peters, D., 80
 Pflästerer, W., 62
 Pietrini, P., 78
 Pilz, K. S., 121
 Popp, M. M., 128
 Preißl, H., 101
 Pretto, P., 162
 Prinz, W., 39, 88

 Rainer, G., 141
 Ressel, V., 101
 Ricciardi, E., 78
 Rieger, M., 39

- Rigamonti, B., 97
Rinkenauer, G., 51, 52, 149
Roether, C. L., 161, 163
Rolke, B., 48, 49, 53, 86
Rüter, J., 105, 109
- Saez Pons, J., 129
Scheibelhofer, G., 138
Schmidt, T., 54, 56
Schmidtborn, L., 169
Schnitzler, H.-U., 44, 45, 62
Schönenberger, R., 122
Schröter, H., 49, 63, 86
Schuetz-Bosbach, S., 37
Schüz, A., 106
Schultz, J., 69, 172
Schultz, S., 137, 143
Schwan, S., 112, 114
Schwarzfischer, K., 55
Seffer, D., 126
Seufert, P., 169
Seydell, A., 54, 56
Seymour, K., 120
Siemers, B., 32, 44
Singer, W., 104
Sireteanu, R., 100
Smith, S., 22
Souman, J. L., 164
Spering, M., 151
Stirn, A., 104
Stolle, A., 108
Stork, S., 173
Strasser, W., 66, 67
Straßer, W., 119
Stritzke, M., 152
- Tanner, T. G., 153
Thiele, J., 165
Thornton, I. M., 115, 118, 121, 159
Trojan, J., 108
Trommershäuser, J., 152
Turesson, H., 106
- Ulrich, R., 48, 49, 63, 86
- de Vignemont, F., 69
Vitello, M. P., 87
Vorberg, D., 57
Vuong, Q. C., 115, 118
- Wachtler, T., 140
Wallraven, C., 74, 119
Weidenbacher, U., 123
Weigelt, M., 41
Welchman, A., 50
Wentink, M., 25
Wertheimer, J., 18
White, B. J., 154
Wichmann, F. A., 92, 174
Widiger, A., 127
Wiener, J. M., 126
Wilke, M., 101
Wolf, R., 166
Wühle, A., 109
- Ziessler, M., 40
Zwickel, J., 88