# 3rd Summer School

# IRTG/CREATE – The Brain in Action

## Collegium Glashütten
## July 11 – 14, 2016

## Program of the IRTG Summer School 2016

Venue: Collegium Glashütten, Wüstemser Str. 1, 61479 Glashütten-Oberelms,
Tel: +49 06082-20-0

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| **July 11, 2016** | until 16:00 h | ***Arrival*** |
| | 16:00 – 18:00 | Student Advisory committee Meetings |
| | 18:00 – 19:30 | ***Dinner*** |
| | 19:30 – 20:30 | ***Welcome*** and Keynote Lecture<br>**Jody Culham**, Western U, Canada<br>“The treachery of images”: Why the brain responds differently to real objects than photos |
| **July 12, 2016** | 07:00 – 09:00 | ***Breakfast***, Students Set-up Posters |
| | 09:00 – 09:20 | **Fabian Helm**, U Giessen, Germany<br>Perceptual discriminability of deceptive and non-deceptive throwing in expert and novice observers is affected by speeded responses |
| | 09:20 – 09:40 | **Seamas Weech**, Queen’s U, Canada<br>Manipulating sensory mismatch in virtual reality through vestibular stimulation |
| | 09:40 – 10:00 | **Mathias Klinghammer**, U Giessen, Germany<br>The use of allocentric information for goal-directed reaching in natural scenes |
| | 10:00 – 10:20 | **Parisa Abedi Khoozani**, Queen’s U, Canada<br>An implicit approximate normalization model for multi-sensory integration across reference frames |
| | 10:20 – 10:50 | ***Coffee Break*** |
| | 10:50 – 11:10 | **Constanze Schmitt**, Marburg U, Germany<br>Processing of multisensory self-motion signals in human observers |
| | 11:10 – 11:30 | **Scott Murdison**, Queen’s U, Canada<br>(Mis-)perception of motion in depth originates from underestimation of binocular extraretinal signals |
| | 11:30 – 11:50 | **Jing Chen**, Giessen U, Germany<br>Attention is allocated ahead of the target during smooth pursuit eye movements: evidence from EEG frequency tagging |
| | 12:00 – 13:30 | ***Lunch Break*** |
| | 13:40 – 14:00 | **Benedict Chang**, Western U, Canada<br>Interception of virtual dynamic objects in atypical gravitational accelerations |
| | 14:00 – 14:20 | **Theresa Gerhard**, Giessen U, Germany<br>Visual object processing and motor development in infancy |
| | 14:20 – 14:40 | **Kate Merritt**, Western U, Canada<br>Automatic on-line motor control in Parkinson’s disease |
| | 15:00 – 18:00 | ***Coffee Break*** + **Poster Session** |
| | 18:00 – 19:30 | ***Dinner*** |
| | 19:30 – 20:30 | **Meeting of the Directorate** |

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| **July 13, 2016** | 07:00 – 09:00 | ***Breakfast*** |
| | 09:00 – 09:20 | **Lindsey Fraser**, York U, Canada<br>Perceived orientation of the fingers is biased towards functional positions of the hand |
| | 09:20 – 09:40 | **Belkis Ezgi Arikan**, Marburg U, Germany<br>Neural correlates of perceiving audiovisual consequences of voluntary movements |
| | 09:40 – 10:00 | **Ahmed Mostafa**, Queen's U, Canada<br>Sensory consequences of hand movement following exposure to visual-proprioceptive discrepancy |
| | 10:00 – 10:20 | **Peter Veto**, Marburg U, Germany<br>Biological motion distorts size perception |
| | 10:20 – 10:50 | ***Coffee Break*** |
| | 10:50 – 11:10 | **Meaghan McManus**, York U, Canada<br>Gravity may influence perceived linearly accelerating vection |
| | 11:10 – 11:30 | **Vivian Paulun**, Giessen U, Germany<br>Motion and shape cues indicate stiffness of elastic objects |
| | 11:30 – 11:50 | **Ramina Adam**, Western U, Canada<br>Large-scale functional network changes during unilateral frontal stroke recovery in nonhuman primates using resting-state fMRI at 7T |
| | 12:00 – 13:40 | ***Lunch Break*** |
| | 13:40 – 14:00 | **Dmytro Velychko**, Marburg U, Germany<br>An explicitly coupled model of sensory-motor primitives |
| | 14:00 – 14:20 | **Arhum Sultana**, York U, Canada<br>Visual perception of transparent objects in real and virtual world |
| | 14:20 – 14:40 | **Vishal Bharmauria**, York U, Canada<br>Egocentric and allocentric encoding of target/gaze location in supplementary eye fields (SEF) of head unrestrained monkeys |
| | 15:00 – 16:30 | ***Coffee Break*** **+ Student Advisory Committee Meetings** |
| | 16:30 – 19:00 | **IRTG Event** |
| | 19:00 – 22:00 | **Barbeque** |

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| **July 14, 2016** | 07:00 – 09:00 | ***Breakfast*** |
| | 09:00 – 09:20 | **Mariann Oemisch**, York U, Canada<br>Prediction error signals in the fronto-striatal system during reversal learning |
| | 09:20 – 09:40 | **Anna Heuer**, Marburg U, Germany<br>Selective weighting of action-relevant feature-dimensions in visual working memory |
| | 09:40 – 10:00 | **Marcus Watson**, York U, Canada<br>Tracking the development of expertise and attention using a context-dependent feature selection task in a 3d interactive environment |
| | 10:00 – 10:20 | **Janis Kan**, Queen’s U, Canada<br>Visual saliency response in the superficial and intermediate superior colliculus |
| | 10:20 – 10:50 | ***Coffee Break*** |
| | 10:50 – 11:10 | **Bianca Ruxandra Baltaretu**, York U, Canada<br>Transsaccadic integration of spatial frequency information: An fMRIa paradigm |
| | 11:10 – 11:30 | **Karén Wilhelm**, Marburg U, Germany<br>Pupil dilation under a perceptual rivalry task as an indirect measurement of locus coeruleus activity in prodromal and manifest neurodegenerative diseases<br>(e.g. Parkinson’s disease) |
| | 11:30 – 11:50 | **Sisi Xu**, Queen’s U, Canada<br>Differential effects of HD-tDCS on mIPS and PMd in reach planning |
| | 12:00 – 13:30 | ***Lunch Break*** |
| | 13:30 – 14:30 | **Gunnar Blohm**, Queen’s U, Canada<br>Sensory-motor computations for reaching |
| | 14:30 – 16:30 | **Student Advisory Committee Meetings** |
| | 17:00 | ***Departure*** |
| | | Canadian participants are offered to stay until July 15, 2016 |

**Abstracts**
**Presenting authors (underlined) are listed in alphabetical order**

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## An implicit approximate normalization model for multi-sensory integration across reference frames

*Parisa Abedi Khoozani*[1], *Dominic Standage*[1], *Gunnar Blohm*[1,2,3]
Center for Neuroscience Studies, Queen's University, Kingston, ON, Canada[1]; Canadian Action and Perception Network (CAPnet)[2]; Association for Canadian Neuroinformatics and Computational Neuroscience (CNCN)[3]

Many brain processes - such as primary sensory processing, attentional modulation, multisensory integration, reference frame transformations, decision making, etc. - can be performed by probabilistic inference. It has been suggested that inference can be implemented in the brain by marginalization across variables through explicit divisive normalization, requiring intractable sums/integrals. Here, we propose an alternative, more physiologically feasible mechanism to perform marginalization. This alternative mechanism (implicit approximate normalization: IAN) is based on well-established parallel computing and machine learning principles and is functionally equivalent to divisive normalization without requiring divisive operations. Specifically, we implemented a multi-layer feed-forward neural network using different neural coding schemes within the same network (i.e. probabilistic spatial codes and probabilistic joint codes) and trained it to perform multisensory integration across different reference frames in one step using a standard pseudo-Newton method with preconditioned conjugate gradient descent. The performance of this network was comparable to a probabilistic population code network, but without requiring non-linear or divisive operations. IAN produces a wide range of behaviors similar to recorded activity in the brain. These behaviors include inverse effectiveness, the spatial correspondence principle, gain-like modulations, super-additivity, and multi-sensory suppression. In addition to key empirical principles of multisensory integration, IAN accounts for quantitative features of cue combination: we observed modulation of neural activity in our network by varying the cue reliability, similar to area MSTd. The strength of IAN is that it performs well with a fraction of the neurons required by explicit methods (i.e. in a network with two cues to be combined in 3-D and 100 units in each dimension, divisive normalization requires $10^{12}$ while IAN requires $10^{3}$ units). Furthermore, IAN doesn't require a neat preconfigured connectivity structure between neurons or explicitly matching population codes for individual neurons, in contrast to explicit divisive normalization. In conclusion, the results of this study demonstrate that marginalizing operations can be done in simple feed-forward networks of purely additive units without the requirement of explicit divisive normalization.

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**Large-scale functional network changes during unilateral frontal stroke recovery in nonhuman primates using resting-state fMRI at 7T**

Ramina Adam[1], Kevin Johnston[2], R. Matthew Hutchison[3], and Stefan Everling[2]
[1]Graduate Program in Neuroscience, Western University, London, ON
[2]Department of Physiology and Pharmacology, Western University, London, ON
[3]Center for Brain Science, Harvard University, Cambridge, MA, US

Spatial extinction is a condition seen in approximately 20-30% of right hemisphere stroke cases in humans and has also been shown in macaque monkeys following a unilateral frontal cortex lesion[1,2]. Extinction is characterized by impaired detection of a contralesional stimulus when two stimuli are presented simultaneously in both the ipsilesional and contralesional hemifield[1]. This results in a profound ipsilesional saccade selection bias that recovers substantially in the months following stroke largely due to brain reorganization[3]. Since stroke leads to structural damage at the focal lesion site and functional changes in remote brain areas connected to the lesion site[3], a network-based approach can provide greater insight into large-scale brain reorganization following stroke. Here, we used resting-state fMRI at 7T and graph theory to identify changes in complex network properties during recovery of the saccade selection bias following a right frontal cortex stroke. We created a nonhuman primate model of ischemic stroke using macaque monkeys by injecting endothelin-1, a potent vasoconstrictor, in the right dorsolateral prefrontal cortex and frontal eye field. Saccade selection bias was measured using a free-choice task in which macaque monkeys were presented with two stimuli, one in each hemifield, either simultaneously or at varying stimulus onset asynchronies. Following stroke, the animals exhibited both a profound ipsilesional saccade selection bias and increased contralesional saccadic reaction times that gradually recovered over time. We used the Brain Connectivity Toolbox to calculate graph metrics, including global and local efficiency, clustering, characteristic path length, modularity, and nodal degree. At week 1 post-stroke, we observed a decrease in global efficiency and small-worldness (decreased clustering, increased characteristic path length). Data collection and analysis of graph metrics is ongoing.

1 Becker E, Karnath H (2007) Incidence of visual extinction after left versus right hemisphere stroke. *Stroke* 38: 3172-3174
2 Schiller PH, Chou I (1998) The effects of frontal eye field and dorsomedial frontal cortex lesions on visually guided eye movements. *Nature Neuroscience* 1(3): 248-253
3 Teasell R, Bayona NA, Bitensky J (2005) Plasticity and reorganization of the brain post stroke. *Topics in Stroke Rehabilitation* 12(3):11-26
4 Carter AR, Shulman GL, Corbetta M (2012) Why use a connectivity-based approach to study stroke and recovery of function? *Neuroimage* 62: 2271-2280

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**Neural correlates of perceiving audiovisual consequences of voluntary movements**

*Belkis Ezgi Arikan, Bianca van Kemenade, Kornelius Podranski, Olaf Steinstreter, Benjamin Straube, Tilo Kircher*

Theories of motor-control suggest an internal forward model where an efference copy signal is used to predict the consequences of voluntary movements. This mechanism leads to an attenuation of the sensory input mainly to save resources for the processing of unexpected stimuli. Sensory attenuation has been observed for auditory, somatosensory and visual modalities both on a behavioral and neural level, however no research has been done yet on the common experience where a self-generated movement leads to multiple sensory consequences. We aimed to investigate neural mechanisms involved in the prediction of voluntary movements leading to unimodal vs bimodal sensory consequences. In addition, we aimed to manipulate the influence of predictability on attenuation by assessing the processing of temporal discrepancies in the movement-consequence relationship. Participants performed hand movements gripping the handle of a custom-made device inside the scanner while seeing an online movie of their hand as they moved. We systematically introduced temporal delays to the recorded movie, and asked participants to judge whether there was a delay between their hand and the online movie. In order to account for the influence of efference copy, we introduced a passive condition where the handle was moved automatically. Half of the trials involved an auditory tone coupled to the movement onset, corresponding to bimodal sensory feedback condition. Preliminary imaging analyses showed reduced activation in areas linked to somatosensory, visual and auditory processing in the active compared to the passive condition, suggesting suppressed activity for the sensory consequences of voluntary movements, both for unimodal and bimodal consequences. This is in line with the behavioral finding showing better delay detection the passive condition. These preliminary results support the hypothesis that efference copy-related predictive mechanisms contribute to BOLD suppression in auditory, visual and somatosensory cortices. Further analyses are planned to assess the influence of subjective experience of delay detection, and the contribution of multisensory feedback in this process.

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**Dual adaptation to opposing visuomotor rotations by skewing movement trajectories**

Maria N. Ayala[1], Denise Y. P. Henriques[2];
[1]Psychology, [2]York Univ., Toronto, ON, Canada

When planning movement, the human central nervous system (CNS) can actively compensate and adapt to two or more distinct perturbations simultaneously ("dual adaptation") though this process only occurs when each visuomotor map is associated with a valid contextual cue. Because not all contextual cues are effective and only more "intrinsic" or motor-based cues tend to be useful to the CNS, we sought to investigate whether movement skewedness allows for dual adaptation of opposing visuomotor rotations. Here, we associated a reach path obstacle which effectively skews the reach trajectory thereby acting as a contextual cue preceding target acquisition. Using a virtual reality paradigm, participants manipulated a projected hand-cursor

using a digitizing tablet in a semi-dark room with an opaque board occluding visual feedback of the hand. Cursor rotations of 30° clockwise and 30° counter-clockwise were each associated with a left and right visual obstacle partially obstructing the direct path to some targets but not all. Participants completed pre-training where they were instructed to reach towards visual targets with aligned feedback, training (misaligned feedback), and post-training where they reached without visual feedback. In the training condition, participants either completed CW trials only, CCW trials only, or both interleaved within the same block ("dual group"). We found significant consistent adaptation and a faster rate of learning to unobstructed targets across all measures for both single and dual distortion groups suggesting that learning was less likely to generalize to obstructed targets. Reach errors significantly decreased over time for the dual group suggesting that movement skew is a sufficient cue for recalling a previous visuomotor map. The single group was able to return to baseline levels while the dual group only partially dual-adapted although this magnitude may be masked by the forced curved path to acquire the most obstructed target. This adaptation was further reflected in the presence of significant aftereffects following training for both single and dual distortion groups independent of the level of target obstruction. Our results suggest that movement skew, an intrinsic cue, is effective at facilitating dual adaptation.

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**Transsaccadic integration of spatial frequency information: An fMRIa paradigm**

B. R. Baltaretu, B. T. Dunkley, & J. D. Crawford
[1]York Univ., North York, ON, Canada; [2]Hosp. for Sick Children, Toronto, ON, Canada

To date, the neural correlates of feature information integration across saccades (i.e., transsaccadic integration, TSI) are relatively unknown. Using fMRI adaptation, we found that right inferior parietal lobule (IPL; specifically, SMG) and extrastriate cortex (putative V4) are sensitive to object orientation in a space-fixed reference frame (Dunkley et al., Cortex, 2016). Here, we used fMRIa to uncover the cortical correlates of spatial frequency in a space-fixed reference frame. Functional data were collected across 11 participants while they observed a vertical grating of a given spatial frequency in the center of the screen, followed by a grating at the same ('Repeat' condition) or different ('Novel' condition) spatial frequency. Participants were required to either fixate in the same position (Fixation task) or to make a saccade to the opposite fixation point (Saccade task). Participants were instructed to decide via a 2AFC task if the subsequent grating was repeated or novel. The Saccade task produced specific, significant ($p<0.05$) summation (repeated > novel; repetition enhancement, RE) in frontal cortex and adaptation (novel > repeated; repetition suppression, RS) in occipito-parietal areas. The Fixation task produced specific, significant ($p<0.05$) summation (RE) in an extensive occipito-parieto-frontal cluster of areas. A region-of-interest analysis was carried out in order to explain parietal and occipital areas found to be involved in transsaccadic memory of object features (Prime et al., 2008; Malik et al., 2015). This indicated regions of significant Novel vs. Repeat effects in additional parietal and occipital areas, possibly explaining our previous TMS results. Overall, TSI of spatial frequency produced similar cortical activation as the pattern for TSI of object orientation in our previous study (although details differed), suggesting a general role for occipital-parietal cortex in spatiotopic TSI of low-level object features.

**Egocentric and allocentric encoding of target/gaze location in Supplementary eye fields (SEF) of head unrestrained monkeys**

*Vishal Bharmauria[1], Amir Sajad[1-4], Jirui Li[1-4], Arora H, Robert Marino[5], Xiaogang Yan[1,3,4], Saihong Sun[1,3,4], Hongying Wang[1,3,4], J. Douglas Crawford[1-4]*

[1]York Center for Vision Research
[2]York Neuroscience Graduate Diploma Program
[3]Canadian Action and Perception Network
[4]Departments of Psychology, Biology, and Kinesiology and Health Sciences, York University, Toronto, Ontario, Canada M3J 1P3
[5]Centre for Neuroscience Studies, Queen's University, Kingston, Ontario, Canada, K7L 3N6

The visual system can memorize the target location in an egocentric (relative to self) or an allocentric fashion (relative to an external landmark).We have recently described gaze-centered (egocentric) coding in the superior colliculus and frontal eye field of the head-unrestrained monkey (Sadeh et al. 2015; Sajad et al. 2015, 2016), but allocentric codes have not been systematically described. Likewise, relatively little is known about spatial coding of head unrestrained gaze shifts in the supplementary eye field (SEF), which produce gaze shifts in various egocentric frames when stimulated (Trujillo et al. 2004) and have also been shown to code object-centered information (Olson). To test the role of SEF in both egocentric and allocentric coding, three dimensional single-unit recordings were performed two head unrestrained monkeys. For the egocentric task, monkeys were trained to make centrifugal gaze shifts toward briefly presented targets distributed throughout potential neuronal receptive fields. A variable memory delay was provided between visual stimulation and the go signal (extinction of initial fixation point) for a gaze saccade. In the allocentric task, an additional visual cue (intersecting vertical and horizontal lines) was presented in one of four oblique directions located11ºfromthe target. During the delay period, a visual mask was briefly presented while the cue was displaced by 8° in one of eight radial directions. At this time, both monkeys are trained, and show a 25% influence of the cue shift on gaze behavior. Approximately 15 neurons have been recorded in the first animal in the egocentric task, which we intend to analyze using a similar model-fitting fashion to Sajad et al. (2015, 2016), with the addition of further allocentric models for data recorded in the allocentric task.

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**Sensory-motor computations for reaching**

Gunnar Blohm

Planning and executing an accurate reaching movement is quite a complex endeavor that the brain seems to solve with disconcerting ease. It involves many different conceptual steps, such as – and not limited to – sensory processing, multi-sensory integration, target selection, decision making, reference frame transformations, integrating initial conditions, respecting biomechanical and neural constraints, and using online feedback to correct errors on the fly. Usually, we attempt to study these conceptual steps in isolation. Here, I will present a novel conceptual framework integrating those steps into a single controller. I will interpret findings from the lab in the light of this framework.
In the first part of my lecture, I will provide an overview of recent insights into sensory-motor computations from the lab. I will then present an exciting new analysis of Magnetoencephalography (MEG) data investigating the visual-to-motor transformation for pointing and I will argue that these data fit nicely into a framework of control theory.

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**Interception of virtual dynamic objects in atypical gravitational accelerations**

Chang, B.J., Stubbs, K., Quinlan, D.J., Culham, J.C.

In many sports, we often intercept dynamic objects with various aerodynamic properties and acceleration vectors. Due to non-gravitational forces such as Magnus forces and air resistance in sports like baseball and ultimate frisbee, these objects often have a downward acceleration vector that differs from Earth's native gravitational acceleration (g = 9.81m/s$^2$). How we compensate for these accelerations and intercept these objects remains unknown. That said, we know that expert groups such as jugglers can attend to and intercept multiple objects at different accelerations. In this study, we examine how untrained individuals intercept dynamic virtual objects at different accelerations. We used a back-projected setup allowing participants to directly interact with a large screen. Optotrak (NDI, Waterloo, Canada) infrared emitting diodes (IREDs) were used to calibrate the projected image to real space as well as to track the hand movements. We tested 3 accelerations at a regular and inverted set up in six conditions (-1.5, -1.0, -0.5, 0.5, 1, and 1.5g). In each condition, participants observed a virtual circle follow a parabolic trajectory velocity at different accelerations. Participants were instructed to intercept the object with their index finger within an allotted space. Preliminary results showed that across all accelerations, inverted (negative) accelerations elicited both slower reaction times as well as an initiation of movement later in the objects trajectory compared to non-inverted (positive) acceleration conditions. These results suggest that additional cognitive processing is required for accelerations which are not often observed in our natural environment. Furthermore, higher gravitational accelerations generally elicited quicker reaction times in both the inverted and non-inverted conditions. In the inverted condition, participants initiated their movement later in the trajectory with greater acceleration. However, this trend was not observed in the non-inverted condition. We are currently expanding this research to include jugglers as an expert group.

**Attention is allocated ahead of the target during smooth pursuit eye movements: evidence from EEG frequency tagging**

*Jing Chen, Matteo Valsecchi, Karl Gegenfurtner*
Department of Psychology, Justus-Liebig-University Giessen

It is under debate whether attention during smooth pursuit is centered on the pursuit target or allocated preferentially ahead of it. Attentional deployment was previously assessed through an additional task for probing attention. This might have altered attention allocation, leading to inconsistent findings. We used EEG frequency tagging to measure attention allocation in the absence of any secondary probing task. The observers pursued a moving dot while stimuli flickering at different frequencies were presented at various locations ahead or behind the pursuit target. In Exp1 ($N = 12$), we observed a significant 11.7% increase in EEG power at the flicker frequency of the stimulus in front of the pursuit target, compared to the frequency of the stimulus in the back. In Exp2 ($N = 12$), we tested many different locations and found that the enhancement was present up to about 1.5 deg ahead (16.1% increase in power), but was absent at 3.5 deg during pursuit. In a control experiment using attentional cueing during fixation, we did observe an enhanced EEG response to stimuli at this eccentricity. Overall, we showed that attention is allocated ahead of the pursuit target during smooth pursuit. EEG frequency tagging seems to be a powerful technique allowing to implicitly investigate attention/perception when an overt task would be disruptive.

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**Size constancy is not accomplished in the early stage of visual processing**

Juan Chen[1], Irene Sperandio[2], Melvyn Alan Goodale[1]
[1]The Brain and Mind Institute, The University of Western Ontario, London, Ontario, Canada
[2] School of Psychology, University of East Anglia, Norwich, UK

Within a certain range, people's perception of the size of an object will not change with viewing distance, even though the size of the image projected on the retina changes. This is called size constancy. To achieve size constancy, it is necessary to compensate for changes in retinal image size with distance by using a range of depth cues. When and where depth cues act on the representation of size is still unclear. Here we used ERPs to address this question. A black disk, which could be small or big, was presented on a white background at a near or far viewing distance. The near-small and far-big conditions had the same retinal size. The near-small and far-small conditions had the same perceived size, as did the near-big and far-big conditions. Participants were tested in a dimly-lit room with all depth cues available. They were asked to indicate whether the disk was small or big regardless of distance (Experiment 1) or to detect the onset of the disk (Experiment 2). In both experiments, we found that within the first 150 ms after stimulus onset, the ERP waves of the two conditions that had the same retinal size overlapped and were significantly different from the other two conditions. After 150 ms, the ERP waves grouped and synchronized according to their physical size (i.e., perceived size) regardless of distance. Because both C1 (which is thought to reflect the response of V1) and P1 (which is thought to reflect the response of extrastriate visual cortex) emerge within the first 150 ms, our results suggest that size constancy is computed after 150 ms in higher-order visual areas beyond V1 and extrastriate cortex. Thus, the size-constancy related fMRI activation that has been observed in V1 may depend on back-projections from these higher-order areas.

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**"The treachery of images": Why the brain responds differently to real objects than photos**

*Jody Culham*
*Professor, Department of Psychology; Brain and Mind Institute*
*Western University, London, Canada*

Psychologists and neuroimagers commonly study perceptual and cognitive processes using images because of the convenience and ease of experimental control they provide. However, real objects differ from pictures in many ways, including the availability and consistency of depth cues and the potential for interaction. Across a series of neuroimaging experiments, we have shown that the brain responds differently to real objects than pictures, both in terms of the level of activation and the pattern. Specifically, compared to pictures, real objects are processed more deeply, evoke different neural patterns, and show stronger neural correlates of their value. Taken together, these results suggest that real objects are more engaging, both perceptually and neurally, and open up new research directions to better understand which aspects of real objects drive these effects.

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**Perceived orientation of the fingers is biased towards functional positions of the hand**

*Lindsey E. Fraser and Laurence R. Harris, York University*

In the absence of visual feedback, the perceived position and size of the hands are biased [1,2]. Previously we showed that perceived orientation of the index fingers is also biased, towards an orientation rotated roughly 5° inwards from upright for both the left and right hands in the frontoparallel plane [3]. Here we tested whether perceived orientation of the fingers in the horizontal plane was similarly distorted in right-handed individuals. Participants sat with their index finger attached to a motor, palm facing down, with the axis of rotation through the middle joint of their finger. A horizontal mirror blocked their hand from view, and a screen reflected in the mirror superimposed at the depth of their hand. At the start of a trial, the participant's finger was rotated to three initial distractor orientations followed by a test orientation. A white bar appeared on the screen and the participant used a mouse to rotate the bar until it aligned with their unseen finger. There were five test orientations (10° outwards, straight ahead, and 10°, 20° or 30° inwards), repeated 10 times each. Both left and right fingers were tested. We found the perceived orientation of the left finger was biased towards an orientation rotated roughly 25° inwards from straight ahead; for the right finger, the bias was towards an orientation close to straight ahead. A follow-up experiment found similar biases when reporting finger orientation with respect to a non-visual target (perceived straight ahead). We argue these biases in perceived orientation reflect a tendency to represent the hands as close to functional positions of operation; the asymmetry between the left and right hand biases is consistent with the theory that the functional role of the two hands may be specialized in right handers.

Haggard P, Newman C, Blundell J, Andrew H (2000) Percept Psychophys 62:363–377.
Longo MR, Haggard P (2012) J. Exp. Psychol. Hum. Percept. Perform. 38:9–13.
Fraser LE, Harris LR, IRTG retreat 2015.

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## Visual object processing and motor development in infancy

*Theresa M. Gerhard*[1], *Jody C. Culham*[2], *Gudrun Schwarzer*[1]
[1]Developmental Psychology, Justus-Liebig-University Giessen, Germany
[2]Department of Psychology and Brain & Mind Institute, University of Western Ontario, London, Canada

From birth, we are challenged to deal with a visual world that is constantly changing. Therefore, successful interactions with our environment require continuous processing of visual object information. Especially during the first year, infants' object processing skills develop rapidly which has led developmental researchers to question the underlying factors driving these impressive achievements. Besides biological maturation as one important factor, a lot of the research on perceptual development has focused on the role of motor experiences (Schwarzer, 2014).
Here, we present infant data on two object processing abilities that play an important role in our everyday engagement with the environment: mental rotation ability, and the discrimination and processing of real objects compared to pictures of those objects. We report that stimulus format effects the visual processing of objects in 7- and 9-month-old infants and ask how far this could be related to differences in infants' fine- and gross motor skills. We also demonstrate an influence of crawling ability on the visual processing and mental rotation of displays of moving, three-dimensional objects in 9-month-old infants. In sum, our findings indicate that motor experiences enhance infants' understanding of the nature, and rotational properties of objects.

Schwarzer G (2014) How motor and visual experiences shape infants' visual processing of objects and faces. Child Dev Perspect 8:213–217 Available at: http://doi.wiley.com/10.1111/cdep.12093 [Accessed April 29, 2015].

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**Perceptual discriminability of deceptive and non-deceptive throwing in expert and novice observers is affected by speeded responses**

*Fabian Helm[1], Jörn Munzert[1], & Nikolaus F. Troje[2]*
*[1] Department of Psychology and Sport Sciences, Justus-Liebig-University Giessen, Germany*
*[2] Department of Psychology, Queen's University, Kingston, Canada*

In many situations in sport, athletes attempt to deceive by manipulating their opponent's process of action anticipation. Athletes may try to convince opponents that one action is being performed while actually carrying out another. In non-speeded judgment tasks, it has shown that the visual system is sensitive to the intentions underlying deceptive movements (e.g., Runeson & Frykholm, 1983; Jackson et al., 2006). Real and deceptive actions typically display a degree of spatiotemporal dissimilarity in terms of motion trajectories and temporal dynamics of the movement kinematics. Currently there is no research that examines how these spatiotemporal dissimilarities influence the discriminability of deceptive movements for novice and expert observers in a speeded judgment task. We addressed this question in the context of handball throws. We motion captured deceptive and non-deceptive throwing movements of novice and elite handball field players and used these to generate realistic 3D avatars. In a perceptual task, we asked novice and expert handball players to judge as quickly and accurately as possible whether observed throws were either deceptive or non-deceptive. The results show that both groups were highly sensitive to deception in throws when responses were given after stimulus offset. Expert observers were significantly better than novices at discriminating throws from both elite and novice performers. In general, discriminability was directly related to spatiotemporal dissimilarities between deceptive and non-deceptive throws. However, discriminability was invalidated when responses were given prior to stimulus offset. Sensitivity for deception dramatically changed for both observer groups. We suggest two possible lines of reasoning. First, early kinematic information in throws were not sufficient enough to discriminate between throws; and second, observers' time to validate their decision was too short.

1 Jackson RC, Warren S, Abernethy B (2006) Anticipation skill and susceptibility to deceptive movement. Acta Psychol 123: 355–371.
2 Runeson S, Frykholm, G (1983) Kinematic specification of dynamics as an informational basis for person–and–action perception: expectation, gender recognition, and deceptive intention. J Exp Psychol 112: 585–615.

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**Selective weighting of action-relevant feature-dimensions in visual working memory**

*Anna Heuer & Anna Schubö*

Planning an action primes feature dimensions that are relevant for that particular action, increasing the impact of these dimensions on perceptual processing (e.g., Memelink & Hommel, 2013). Here, we investigated whether this mechanism of selective action-related processing also affects the short-term maintenance of visual information.

In a dual-task paradigm consisting of a memory and a movement task, participants were to memorize items defined by size or color while preparing either a grasping or a pointing movement. Whereas size is a relevant feature-dimension for grasping (Smeets & Brenner, 1999), color can be used to localize the goal object and guide a pointing movement (White, Kerzel, & Gegenfurtner, 2006). In Experiment 1, the memory task was embedded within the movement task to test for a general effect of action intentions on the maintenance of visual information. In Experiment 2, the movement to be performed was only indicated during the retention interval to test whether a weighting of feature dimensions could also be introduced at the representational level during maintenance.

In both experiments, memory for items defined by size was better during the preparation of a grasping movement than during the preparation of a pointing movement. Conversely, memory for color tended to be better when a pointing movement was being planned than when a grasping action was being planned. These findings show that action-relevant feature-dimensions are preferentially maintained in visual working memory, ensuring the availability of information needed for upcoming actions. The weighting of representations according to action-relevance cannot only be attributed to perceptual enhancement at encoding (Experiment 1), but can also be implemented during maintenance (Experiment 2). Thus, our actions continue to influence visual processing beyond the perceptual stage.

1 Memelink J, Hommel B (2013) Intentional weighting: a basic principle in cognitive control. Psychol Res 77:249–259.

2 Smeets JB, Brenner E (1999) A new view on grasping. Motor Control 3:237–271

3 White BJ, Kerzel D, Gegenfurtner KR (2006) Visually guided movements to color targets. Exp Brain Res 175:110–126.

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**Visual saliency response in the superficial and intermediate superior colliculus**

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The superior colliculus (SC) is a phylogenetically old midbrain structure that plays a central role in vision, attention, and orienting. The SC has visual representations in the superficial-layers (SCs), and sensorimotor representations linked to the control of eye movements and attention in the intermediate-layers (SCi). Cognitive and computational neuroscience postulates the existence of a visual saliency map that guides visual orienting towards the most visually conspicuous stimuli, and a priority map that combines bottom-up saliency and top-down relevance to allow internal processes such as goals and expectations to also guide behavior. We hypothesize that the SCs embodies the role of a bottom-up saliency map while the SCi embodies the combined priority map. To test this hypothesis, we compared SCs and SCi activity in response to task-irrelevant salient stimuli. Monkeys viewed a wide-field arrangement of stimuli (210 radially-arranged items spanning ~40-50deg) extending beyond the classic receptive field (RF). The stimuli were oriented color-bars (~0.4x1.2deg) that formed a perceptual "pop-out" array the monkeys had to ignore; i.e., reward was contingent upon maintaining gaze on central fixation. We compared visual representations in SCs and SCi when 1 to 4 salient pop-out stimuli appeared equally spaced within the array. We also compared this to an array of homogenous items with no pop-out. Only SCs neurons showed a reliable preference for the visually salient but goal irrelevant pop-out stimulus. Also, this representation in the SCs was the same in the presence of 1 to 4 pop-out items. It is important to note that the pop-out stimuli in the present task was goal IRRELEVANT. In the SCi, we only observed a response to a single salient pop-out stimulus; this response was absent once there were 2 or more salient pop-out items. Next, we will examine how activity in the SCs and SCi changes when the salient stimuli become also goal RELEVANT by being the target of a saccade that will lead to differing amount of reward.

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**Inconsistency effects on indirect perception of box weight.**

*Sophie Kenny, Nikolaus F Troje*

There is evidence that observers are sensitive to the internal consistency of shape and motion, two correlated internal properties of humans in action. Indeed, when shape and motion of walkers are exchanged between performers, perceived attractiveness decreases (Klüver et al. 2016). Does internal consistency also matter for perception of other actions?

We know that observers are able to indirectly perceive object properties in point-light displays, such as box weights from lifting actions. Runeson and Frykholm (1981), who worked with biological motion point-light displays, attributed this ability to what they called the Kinematic Specification of Dynamics. The KSD assumes that dynamics are inferred from observed kinematic patterns by means of an internal model of the relations between body shape and body motion.

Using MoSh, that is, Motion and Shape Capture from Sparse Markers (Loper, Mahmood, & Black, 2014) we created animated, life-like human avatars from the surface motion capture data of performers lifting boxes of various weights. We generated consistent stimuli using the shape and movement from the same performer, and inconsistent stimuli by combining the shape and motion from performers of very different body shape.

Results showed that internal consistency had an effect on the indirect perception of box weight using visual information from shape and motion, indicating that the visual system may be generally sensitive to departures from expected correlations of performers' shape and motion.

1 Klüver M, Hecht H & Troje N (2015) Internal consistency predicts attractiveness in biological motion walkers. *Evolution and Human Behavior* 37 : 40-46.

2 Loper, M. M., Mahmood, N., & Black, M. J. (2014). MoSh: Motion and Shape Capture from Sparse Markers *ACM Transactions on Graphics* 33: 1-10.

3 Runeson, S., & Frykholm, G. (1981) Visual perception of lifted weight. *Human Perception and Performance* 112: 585-615.

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**The use of allocentric information for goal-directed reaching in natural scenes**

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When interacting with objects in daily life situations, our brain relies on information represented in two main classes of reference frames: an egocentric (relative to the observer) and an allocentric (relative to objects or the environment) reference frame. Previous research demonstrated that humans use allocentric information when reaching to visual targets; but most of the studies are limited to 2D space. In two virtual reality experiments, we investigated the use of allocentric information for reaching in depth and the role of different depth cues (vergence/retinal disparity, object size) for coding object locations in 3D space. We presented participants a scene with virtual objects on a table which were located at different distances from the observer and served as reach targets or allocentric cues. After visual exploration and a short delay the scene reappeared, but with one object missing (= reach target). In addition, the remaining objects were shifted horizontally or in depth. When objects were shifted in depth, we also independently manipulated object size by either magnifying or reducing their size. After the scene vanished, participants reached to the remembered target location on the blank table. Reaching endpoints deviated systematically in the direction of object shifts indicating the use of allocentric information. This was independent of observer-object-distance and dependent on object size manipulation suggesting that both vergence/retinal disparity and object size provide reliable depth cues when coding reach targets in an allocentric reference frame in reachable 3D space.

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**Reward facilitates implicit learning and search efficiency in a contextual cueing task.**

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Participants are faster and more accurate in finding and reporting the orientation of targets which are embedded in contexts that have been encountered before. This observation is known as contextual cueing. While contextual cueing can be seen as an effect of an observer's selection history and reward has been shown to affect attention guidance in other tasks, it is yet unclear how reward affects contextual cueing. In two experimental sessions we instructed participants to find and report the orientation of a T-shaped target embedded in a context of L-shaped distractors as fast and as accurately as possible. Half of the target-distractor layouts were repeated over time whereas the other half was randomly generated before presentation. One of three unique colors in each context was consistently paired to one of three levels of reward (low, medium, high). Contextual cueing was measured by response times and response accuracy. As participants were allowed to move their eyes, eye-movements were co-registered and analyzed separately. We found that participants were faster and more accurate in reporting target orientations in repeated than in novel contexts. Reward further facilitated contextual cueing, leading to more discernible

differences between contexts with increasing reward. Similarly, participants moved their eyes more directly towards the target following repeated compared to novel contexts with larger effects for high versus low reward trials. These findings suggest that previously encountered scene regularities are learned and used by observers to improve search efficiency in subsequent expositions to the same scenes and that those regularities are prioritized if they are considered more valuable.

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## Going against the grain – Texture orientation affects direction of exploratory movement

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In haptic perception sensory signals depend on how we actively move our hands. For textures with periodically repeating grooves, movement direction can determine temporal cues to spatial frequency. Moving in line with texture orientation does not generate temporal cues. In contrast, moving orthogonally to texture orientation maximizes the temporal frequency of stimulation, and thus optimizes temporal cues. Participants performed a spatial frequency discrimination task between stimuli of two types. The first type showed the described relationship between movement direction and temporal cues, the second stimulus type did not. We expected that when temporal cues can be optimized by moving in a certain direction, movements will be adjusted to this direction. However, movement adjustments were assumed to be based on sensory information, which accumulates over the exploration process. We analyzed 3 individual segments of the exploration process. As expected, participants only adjusted movement directions in the final exploration segment and only for the stimulus type, in which movement direction influenced temporal cues. We conclude that sensory signals on the texture orientation are used online during exploration in order to adjust subsequent movements. Once sufficient sensory evidence on the texture orientation was accumulated, movements were directed to optimize temporal cues.

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## Gravity may influence perceived linearly accelerating vection

*Meaghan McManus* and *Laurence R. Harris*

The otoliths in the vestibular system respond to linear acceleration and also signal head orientation relative to gravity, since gravity itself is an acceleration. This suggests that when gravity is aligned with the direction of motion, such as when lying prone or supine and translating up or down, that some of the gravity acceleration could be misinterpreted as linear acceleration. Here we compared participants' performance in a virtual move-to-target task while they were either standing or lying prone or supine (gravity in the same or opposite direction as the simulated motion acceleration). While wearing an oculus rift (virtual headset), participants saw a projection of a hallway that had a target at varying distances from them (10 - 80m). When the participant was ready the target was removed and they accelerated forward at $9.8 m.s^{-2}$. The participant pressed a

mouse button when they reached the remembered location of the target. Regardless of body posture participants had the sensation of moving forwards while upright down a hallway.
Based on the possible interaction between optic flow and gravity information we predicted that when prone participants would perceive themselves to travel further compared to standing and when supine would perceive themselves to travel less far compared to standing. However results showed that participants undershot relative to standing in both the supine and prone postures. These results suggest that gravity may influence the perception of linear acceleration in these conditions, and contribute to the difference in performance however it cannot be the only effect. Previous studies have shown that when gravity cues become unreliable visual flow information is weighted more strongly (Oman et al., 2003). In our experiment gravity cues may be more unreliable in the prone and supine body positions, particularly when combined with the perception of moving horizontally. Therefore a follow-up study is currently underway where all participants are standing but their heads are either straight, or tilted forwards, or backwards to separate gravity and body cues. It is hypothesized that we will see a pattern of results as predicted in the previous experiment. Overall these findings will allow us to model the contributions of the head and body to linear vection.

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Oman, C. M., Howard, I. P., Smith, T., Beall, A. C., Natapoff, A., Zacher, J. E., & Jenkin, H. L. (2003). The role of visual cues in microgravity spatial orientation.

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**Coding of extrinsic and intrinsic object features by the visual system**

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The current study will investigate whether ventral and dorsal visual streams code non-overlapping object features characterized by the respective functions of these streams. Ventral stream for perception is hypothesized to code stable, intrinsic object features such as familiar size that directly contribute to object recognition, while invariantly responding to transitory, extrinsic features such as object distance and physical size (i.e., retinal image). In contrast, dorsal stream for action is thought to code temporary, extrinsic features such as distance and physical size that directly define motor programming of a potential action towards an object, while invariantly responding to objects' stable features such as familiar size. Indeed, it has been shown that lateral and medial regions of ventral temporal cortex (VTC) preferentially respond to images of small and large familiar objects regardless of their retinal sizes, whereas superior parieto-occipital cortex (SPOC) and anterior intraparietal sulcus (aIPS) code object distance and physical size. In the current study we manufactured fMRI-scanner-friendly objects with canonical familiar sizes (i.e., playing die vs Rubik's cube) and we will manipulate their physical size (e.g., playing dice 2x2 cm vs 7x7 cm) and distance (i.e., near vs far). We will use representational similarity analysis (RSA) to investigate whether VTC, SPOC, aIPS show distinct neural patterns of activation to the levels of object features that are the most informative for their respective functions, specifically familiar size for recognition, distance for reaching and physical size for grasping.

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### Automatic on-line motor control in Parkinson's disease

*Kate E. Merritt, Ken N. Seergobin, Melvyn A. Goodale & Penny A. MacDonald*

Rather than our actions being under the strict control of a predefined motor plan, fast and precise modifications can be processed and implemented on-line. In healthy controls, such an ability to rapidly correct movements on-line can occur both with and without conscious cognitive control. In contrast, patients with Parkinson's disease (PD) are thought to be selectively impaired in consciously-mediated on-line motor control, while their ability to perform subconscious on-line adjustments remains intact. Here, we argue that such a conscious-subconscious interpretation in PD is problematic. We propose that the alleged deficits in automatic on-line motor control are not due to the consciousness of the correction, but rather are attributable to bradykinesia associated with PD. To address this idea, we tested 12 patients with PD and 12 matched controls using a modified double-step paradigm. To eliminate any confounding effects of limb-bradykinesia, we introduced two sizes of target perturbations: small (3.5 cm) and large (7 cm) to occur during their initial saccade. We empirically confirmed that small perturbations fell below the threshold for conscious perceptual awareness, whereas large perturbations exceeded the threshold for awareness. To this end, we induced conscious online motor corrections in a way that was independent of hand movement initiation. Critically, functional analyses of reach trajectories revealed that PD patients performed on-line corrections similar to that of healthy matched controls -regardless of the consciousness of the action. Similarly, on-line corrections did not increase overall movement durations for the PD group across any of the condition types, suggesting a degree of automaticity in their performance. Taken together, these results suggest that when the target displacement does not depend on hand movement initiation, PD patients perform on-line corrections with the same automaticity regardless of the target jump size or perceptual awareness.

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### Simultaneous allocation of attention to perceptual and saccade goals in a same-different matching task: Effects on perceptual and saccade performance.

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In the current study we investigated whether visual attention can be simultaneously allocated to spatially distinct perceptual and saccade target locations, and how attending multiple locations for perception and action influences perceptual performance over time and saccade performance (i.e., accuracy, precision, and curvature). To this end, participants performed a same-different matching or a single discrimination task during the preparation of a saccade. A central perceptual target cue instructed participants to covertly attend to one of three possible target locations. Thereafter, a central saccade target cue instructed them to perform a saccade either to the same (congruent) or a different (incongruent) target location. The discrimination target(s) appeared after the saccade target cue, in a time range of 0 – 120ms for 50ms. In incongruent trials, one discrimination target appeared at the perceptual target location and one at the saccade target location. Participants matched the identity of both discrimination targets (i.e., same or different). In congruent trials, only one discrimination target appeared at the cued location. Participants indicated the identity of the discrimination target (i.e., E or 3). Congruent trials served as baseline. Our results showed that participants' overall matching performance for incongruent trials was above chance; however, only half of the participants were able to perform the task clearly above chance, while the other half performed around chance. In general, perceptual performance in the single discrimination task was better than in the matching task. Moreover, the time-course of perceptual performance in the matching and the discrimination task substantially differed between well and badly performing participants. With respect to saccade performance, we found that saccade accuracy and saccade precision were deteriorated in the matching task compared to the discrimination task, and saccades curved away from the covertly attended perceptual target location. Our findings demonstrate pronounced interindividual differences in the ability to simultaneously attend to multiple locations for perception and action. Moreover, these interindividual variations in perceptual performance are also evident in substantial differences in the time-course of attentional allocation to one compared to multiple perceptual and motor goal locations.

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**Sensory consequences of hand movement following exposure to visual proprioceptive discrepancy**

*Ahmed Mostafa, Bernard Marius 't Hart, Denise Y.P Henriques*

In visuomotor adaptation, when subjects first make a reach there is a mismatch between actual and predicted sensory feedback. Subsequently they adapt to accurately reach the target, and update their predictions about sensory feedback which informs changes in hand localization. Additionally, our lab and others have shown that hand proprioception recalibrates to visual feedback ("proprioceptive recalibration"). Here we quantify the contributions of updated predicted sensory consequences and recalibrated proprioception to hand localization. If there is no discrepancy between predicted and actual visual feedback of the hand during reach training, then any changes in hand localization are due to proprioceptive recalibration. In experiment 1, our subjects trained to actively reach to a target with a 30° rotation. In experiment 2, they were exposed to visual and proprioceptive discrepancy only (cross-sensory error signal; Cressman & Henriques, 2010), but since the apparatus moved the participants' hands there was no prediction about visual consequences to update. Then we measured changes in hand localization, also with both active and passive placement of the adapted hand; i.e. with and without predictions. Hand localization changed substantially in all conditions. With active training, the change for passive placement accounted for two thirds of the change for active placement. As expected, passive training did not lead to a difference between active and passive localization, suggesting both reflect proprioceptive recalibration only. This shows that cross-sensory error signals affect motor performance and lead to proprioceptive recalibration, and thus seem to be an unappreciated aspect of motor learning.

**(Mis-)perception of motion in depth originates from underestimation of binocular extraretinal signals**

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Perception of motion in the depth dimension is essential to moving through the world. To estimate 3D motion, the brain uses extraretinal signals – including ocular vergence, horizontal and vertical version – to interpret binocular inputs. However, the extent to which these extraretinal signals contribute to perception of motion in depth is unclear. To answer this question, we asked 13 participants to estimate 3D motion without any visual references, forcing them to utilize extraretinal cues to reconstruct the spatial motion.
Participants sat in complete darkness while fixating one of 9 locations (horizontal version angles of -30°, 0° or 30° and vergence angles of 8.8°, 4.8° or 3°). We moved an LED around fixation along an arc in the horizontal depth plane with one of 36 possible trajectories. After target motion, participants were instructed to reproduce their perception of the motion in space using a touchscreen. After observing version-induced systematic errors in estimated trajectories relative to the spatial motion, we compared these perceptions to the output of a 3D kinematic eye-head-body (forward and inverse) model describing the predicted target motion either based solely on retinal motion or instead based on a transformation of retinal motion into spatial coordinates. For the transformation model, we varied the contributions of reference vergence, horizontal version and the gain of motion in depth to the inverse model and found the set of extraretinal parameters that resulted in a predicted trajectory best representing the reproduced motion.
Across participants, we found that perceived trajectories were best captured with a version estimate of 19.5° ± 6.0° (mean ± SD) for a true horizontal version of 30°, a gain term accounting for 65% ± 14% of the motion in depth, and a reference vergence angle of 6.7° ± 1.4. These findings were consistent with previous studies reporting underestimates of horizontal version and depth changes, and point toward a partial transformation of retinal motion signals into spatial coordinates resulting in substantial errors in motion perception.

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***Prediction error signals in the fronto-striatal system during reversal learning***

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Prediction errors (PEs) are thought to underlie learning by signaling the difference between predicted and actually received reward outcomes; a process pivotal to updating future predictions. PE signals have been reported across all areas of the medial and lateral prefrontal cortex (PFC) and dorsal and ventral striatum. However, it has been unclear whether PEs are

qualitatively similar across areas of the fronto-striatal system and whether feature-specific PEs are encoded preferentially in separate areas of this system.
To clarify these questions, we characterized spiking activity of neurons in the macaque fronto-striatal system with a feature-based reversal learning task. In this task, a monkey was presented with two grating stimuli that differed in color, location, and grating motion. One of two stimulus colors was alternately rewarded in a block design fashion, with uncued reward reversals between blocks. Learning is assessed using an expectation-maximization algorithm [1] that provides an estimate of the probability of a correct outcome on a trial-by-trial basis. Positive PEs (pPEs) were defined as outcome signals following the rare correct outcomes during learning, while negative PEs (nPEs) were the rare erroneous outcomes after learning at high performance. PE signals were identified as feature-specific when they were selectively larger for e.g. a specific rewarded color.
Neurons encoding pPEs were more prevalent than neurons encoding nPEs and similar proportions of neurons encoded PEs by suppressing and amplifying spiking. However, pPEs were more prevalent in striatum and lPFC compared to mPFC and the proportion of feature-specific PEs was larger in mPFC and lPFC than in striatum. The current results suggest that neurons in the fronto-striatal system contribute together to signaling errors of predicted outcomes, but carry dissociable content about the feature origin of this error.
To verify and further describe these results, as a next step, we will identify PE neurons based on their tracking of outcome likelihood. This allows a trial-by-trial measure of PEs and resembles a more physiologically relevant PE signal that gradually changes with learning and probability of reward.

1 Smith et al., 2004, J Neurosci

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**Motion and shape cues indicate stiffness of elastic objects**

*Vivian C. Paulun, Filipp Schmidt, Jan Jaap R. van Assen, Roland W. Fleming*

The behavior of non-rigid materials, like jelly, is determined by their physical properties and the external force applied. Which visual cues do we use to infer an object's softness from its behavior? We computer-simulated cubes of varying softness exposed to different types of an external force: (1) a rigid cylinder pushing downwards into the cube to various amounts (shape change, but little motion), (2) a cylinder quickly retracting from the cube (same initial shapes, differences in motion). Thus, either shape- or motion-related cues to stiffness were dominant in the animations. Observers rated how soft/hard the cubes appeared. In the first scene, ratings were based mainly on the magnitude of the perturbations rather than the intrinsic material properties of the cube, i.e. observers assumed a constant force moving the cylinder. In the second scene, with motion being the dominant cue, perceived softness depended strongly on the amplitude and frequency of the cube's motion, which varied with its stiffness. Generally, cues related to curvature, and frequency and damping of oscillations dominated the judgments and outweighed the influence of the material's optical appearance. Our results suggest a rich internal representation of the properties and behavior of non-rigid materials.

**Processing of multisensory self-motion signals in human observers**

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The processing of self-motion information is of critical importance in everyday life. One of the aspects of self-motion is travelled distance. Previous studies have revealed that humans are able to use visual, auditory, and somatosensory information to reproduce simulated travelled distances (Bremmer and Lappe, 1999; Von Hopffgarten et al., 2011; Paul 2015) .The neural basis of this behavioral performance is barely understood. Here we use EEG to monitor the processing of multisensory (visual and auditory), simulated self-motion. We hypothesize multisensory interactions, i.e. enhanced (or suppressed) signal amplitudes for bimodal as compared to unimodal conditions. In addition, we ask, if the predictability of the self-motion modulates the signature of the event related potentials (ERPs).

This is an ongoing study. In our experiments, we present stimuli in three different modality settings. In the first setting, only a visual stimulus is presented that consists of a random dot pattern simulating self-motion across a ground plane. The second setting is purely auditory. Here, a sinusoidal tone is presented whose frequency is proportional to the simulated speed of self-motion. The third setting is bimodal, i.e. participants are presented both the visual and the auditory stimulus.

We record ERPs in three different behavioral conditions. In the first condition, subjects passively view the self-motion stimulus (visual, auditory, or bimodal. Termed: *Passive condition*). In the second condition, subjects have to reproduce via a joystick the previously observed travel distance (*active condition*). This behavioral response in the active condition (joystick deflection) is recorded and is presented to the subjects later in the experimental session (*replay condition*). Accordingly, the stimulation pattern in the second and third condition are physically identical, with the exception, that subjects control the stimulus themselves (active condition) or not (replay condition).

We currently have started our data analysis. In a first step, we want to compare the ERPs as induced in the active and in the replay condition. In further analyses we will determine the distance reproduction results with respect to the different sensory modalities. We expect a better behavioral performance in the bimodal condition, which should be paralleled in the ERPs.

1 Bremmer F, Lappe M (1999) The use of optical velocities for distance discrimination and reproduction during visually simulated self motion. ExpBrain Res 127:33–42.

2 Paul J (2015) Psychophysik der visuell-taktilen Eigenbewegungswahrnehmung. Master thesis, Philipps-Universität Marburg.

3 Von Hopffgarten A, Bremmer F, von HA, Bremmer F, Von Hopffgarten A, Bremmer F, Cues A (2011) Self-Motion Reproduction Can Be Affected by Associated Auditory Cues. Seeing Perceiving 24:203–222.

**Unitary vs. modality-specific semantic knowledge in object perception: On the neural correlates of perceiving pictures, spoken and written words**

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Some of the core questions in cognitive science evolve around the nature of conceptual knowledge, which is assumed to augment a wide variety of mental processes, ranging from language comprehension and production to visual perception and action planning. Previous research is divided as to whether there are distinct semantic representational systems for different sensory input modalities in the brain, or a convergence of semantic processing within a common conceptual representational space (Patterson et al., 2007). However, most studies have focused on comparing visually presented words and pictures (Devereux et al. 2013), even though this does not constitute an orthogonal comparison of sensory input modalities, but rather a comparison of different stimulus formats. Far fewer studies have compared the processing of spoken words with visually presented pictures (Costanzo et al. 2013). However, to the best of our knowledge, no studies have yet undertaken a direct, within-participants comparison of visually presented pictorial material with linguistic material of different input modalities. In addition, many studies relied on explicit semantic tasks such as category judgments or matching tasks, which added a layer of processing beyond “pure” perception that could potentially inflate the activation of amodal neural networks by requiring participants to generate an abstract stimulus judgment unrelated to perceptual processing of the stimuli. The present fMRI experiment addressed the question of whether the conceptual system is a unitary system comprising amodal representations that are used for multiple perceptual processes. To this end, eleven participants (preliminary data; 4 women, mean age: 24 years) were presented with the same objects in different modalities/formats in order to disentangle crossmodal and modality-specific activations in response to pictures, visually presented words and auditorily presented words. Using conjunction analyses, we found robust semantic activation common to all three input conditions in the bilateral posterior superior temporal gyrus. In addition, there were modality-specific activations for the two visual conditions in the right fusiform gyrus and format-specific activations for the two linguistic conditions in the left and right posterior middle temporal gyrus. Activations in Heschl’s gyrus and the inferior occipital gyrus most likely reflect intermediate, pre-semantic stages of visual and auditory processing respectively. Our data are consistent with a hierarchically structured, unitary system of semantic representations not only for visually perceived pictures and words, but also for the auditory perception of spoken words referring to the same objects. In addition, further analyses will explore the geometry of this semantic space with respect to animacy, thus testing the hypothesis of a common animacy hierarchy within crossmodal semantic space.

**The influence of group membership on emotional processing in the extended mirror neuron system**

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Successful social interactions are based on both partners' ability to clearly communicate and understand meanings and intentions. This process crucially depends on the accurate recognition and interpretation of each other's facial expressions, which is hypothesized to be achieved by recruitment of an extended mirror neuron system. This mechanism is further believed to be susceptible to social factors, such as group membership and identification with a respective interaction partner.

During the acquisition of functional magnetic resonance imaging (fMRI) data, 178 healthy subjects were presented with videos of neutral and angry faces (emotion observation). A colored frame around the faces indicated whether the shown person belonged to the subject's ingroup (IG) or outgroup (OG), which were defined by a minimal group paradigm. Subjects were also asked to display neutral and angry facial expressions themselves (emotion execution).

In order to identify an extended mirror neuron system for emotional processing, we computed conjunctions of emotion observation and execution for both angry > neutral and neutral > angry expressions (uncorrected, $p>0.001$, <50 voxels). This approach revealed two distinct networks 1. emotion activation network (angry > neutral): strongest activations for the processing of angry faces were found in bilateral inferior frontal gyrus, bilateral supplementary motor area, right precentral gyrus and bilateral supramarginal gyrus 2. emotion deactivation network (neutral > angry): strongest deactivations for the processing of angry faces were found in bilateral superior frontal gyrus, right mid orbital gyrus and bilateral superior temporal gyrus. In addition, the emotion x group interaction revealed a cluster in the left anterior cingulate cortex (ACC) extending into bilateral mid orbital gyrus, which overlapped with the deactivation network only when observing ingroup faces.

These results indicate the existence of two distinct neural networks involved in the observation as well as execution of angry facial expressions and, thus, support the notion of an extended mirror neuron system for emotional processing. Furthermore, we found evidence for a differential functional role of the ACC which only showed sensitivity to emotional valence when observing ingroup members.

**Visual perception of transparent objects in real and virtual world**

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In modern life of digital media, viewers often see portrayals of high-fidelity transparent objects in the 3D worlds of games and cinema. Rendering of water and other fluids has received considerable attention in the last decade. For me, the question of interest is: How are humans able to visualize the shape of water surfaces in real world? Given this information based on human judgments related to the process of shape recovery, what specific aspects of the natural optical environment should be provided to the user to efficiently and realistically render the transparency of water? When objects are viewed stereoscopically, the left and right eye images combine to provide disparity that can be used to determine depth. Precise matching is difficult in the case of transparency due to the refraction at the water's surface. Our work is grouped with previous work on photo-realistic image-based surface shape reconstruction that measured the perception of surface orientation of thin transparent glass objects under stereoscopic viewing. In this talk we present a system that uses a gauge figure task to estimate and reconstruct the perceived shape of the refractive surface of still images of water in 3D virtual space. We use these data to test hypotheses about the ability to recover surface shape stereoscopically that arise from a theory of light path triangulation.

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**An Explicitly Coupled Model of Sensory-Motor Primitives**

*Dmytro Velychko, Benjamin Knopp, Dominik Endres*

We focus on modular motor primitives as building blocks for action generation (Endres 2013). To learn dynamical motor primitives and sensory-motor adaptation we develop a probabilistic model of sensory state evolution and motor output as dynamical systems with explicit functional mappings and couplings. This is an extension of our previous work on the Coupled Gaussian Process Dynamical Model (CGPDM) (Velychko, 2014). In contrast to that study, partial predictions in this new model are not integrated out, and thus – learned explicitly. This allows easy exchange and coupling of motor primitives for different body parts and tasks, as well building sensory-motor primitives, where the environment is modelled in a separate dynamical model. Variational treatment allows faster learning with reduced memory. We call this new model the Variational Coupled Gaussian Process Dynamical Model with Explicit Mapping Functions (veCGPDM) (Velychko, 2016). Conditioning on the sensory state would allow us to infer or learn the optimal control policy thereby bridging the gap between the optimal control and movement primitives.
To test this model we performed a set of psychophysical experiments. In a 2-AFC design participants were presented with two side-by-side 1,5s videos of a walking human, a real mocap and a generated by the model, and asked to point a natural movement. The artificial stimuli were generated with different size of memory for the dynamics (2-16 points) and the latent (4-16 points) mappings. We performed the psychometric fit with ELBO, SoftMin and Dynamic Time Warp

Error regressors, and report good fit with the SoftMin function; there is no significant increase in the model performance for memory greater than 8 points.
Next, we demonstrate the modularity of the model, i.e. the ability of the model to combine motor primitives learned separately. We train out model on such activities: straight walking to learn the legs dynamics, walking and waving with both hands for upper body part waving primitive. Then we perform additional learning only for the coupling weights, which is very fast, to generate the walking-and-waving movement. We report the coupling weights learned for this model in details.

1 Endres D, Chiovetto E, and Giese MA (2013) Model selection for the extraction of movement primitives. Frontiers in Computational Neuroscience, 7:185.
2 Velychko D, Endres D, Taubert N, and Giese MA (2014) Coupling Gaussian process dynamical models with product-of-experts kernels. In Proceedings of the 24th International Conference on Artificial Neural Networks, LNCS 8681, pages 603-610. Springer.
3 Velychko D, Knopp B, Endres D (2016) The Variational Coupled Gaussian Process Dynamical Model. Submitted to Neural Information Processing Systems (NIPS), 8+10 pages.

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**Integrating lexical and facial information for emotion processing via cross-modal priming – A developmental perspective**

*Michael Vesker, Daniela Ludwig, Franziska Degé, Christina Kauschke, Gudrun Schwarzer*

The ability to perceive emotional information in faces is highly relevant because it is crucial for non-verbal social communication. It is known that information on emotional expression is especially influential in young children, effecting aspects such as recognition accuracy (Freitag & Schwarzer, 2011). However, in natural circumstances perceiving facial emotions often occurs in conjunction with perceiving speech by that same person. The influences between these modalities have already been demonstrated using cross-modal priming in adults (Carroll & Young, 2005). However, as children develop both modalities it is important to understand the mutual influence of these modalities on each other. Thus, it is the goal of the present study to investigate the effect of auditory verbal priming using emotion words on the perception of facial expressions in an emotional categorization task with multiple age groups of children as well as adults. Thus far, our results have children showing slower reaction times for semantically incongruent priming (e.g. positive word priming negative face) than for congruent (e.g. positive word priming positive face) or unprimed conditions. This difference suggests that the semantic priming observed here is due to interference from incongruent words, rather than facilitation by congruent words. Heightened interference from positive words was observed in the group of 6 year old children relative to 9 year old children (where we see greater interference from negative words), demonstrating a positivity bias in younger children.

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**Biological motion distorts size perception**

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Perception of size is neither stable nor objective, as demonstrated by several illusions. In most of the known cases, the change in perceived size is caused by contrast or constancy effects. Higher level attributes of an object can, however, also result in distorted size perception: people and objects of greater power or subjective importance appear as larger. As biological motion cues carry special importance in visual processing, we hypothesize that ecologically valid biological motion stimuli might appear larger than similar motion stimuli without ecological validity.
We tested this hypothesis with two different paradigms in separate experiments. For each trial of Experiment 1, participants viewed an either upright or inverted point-light walker. Following a random dot mask, they judged the size of the previously seen walker by adjusting a rectangle both in width and in height. Upright walkers were estimated to be significantly larger in both dimensions than inverted walkers.
In Experiment 2, two walkers with different orientations were shown above and below fixation, followed by two target circles presented at the same locations. The size of the walkers was fixed, while target circles varied in diameter. Participants gave a non-speeded forced choice response as for which circle was larger. Perceived size of target circles following an upright walker was significantly smaller. Conforming to the size contrast effect, this shows that upright walkers were perceived as larger.
Results display that ecological validity in biological motion leads to larger perceived size, providing novel evidence for the relativity of size perception and further supporting the existence of a "life detector."

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**Tracking the development of expertise and attention using a context-dependent feature selection task in a 3d interactive environment**

_Marcus R Watson_, _Thilo Womelsdorf_

Experts attend to the objects of their expertise differently than novices. Chess masters look at chess boards more efficiently than beginners, native language speakers hear the relevant parts of speech where others hear noise, etc. Surprisingly little is known about how these appropriate attentional allocations are learned: how one learns to focus on the task-relevant aspects of stimuli and ignore the irrelevant aspects. Here we investigate this learning of optimal attentional allocations in a short time frame, during which participants acquire expertise in a simple object selection task. Participants play a video game in which they navigate through a number of 3D environments and choose between objects they encounter in these spaces. These choices are either rewarded or not, and through trial and error participants eventually learn the rules governing which objects will be rewarded in which environments (e.g. "in a grass field, triangular objects will be rewarded"). We will record participants' accuracy on each trial and their eye movements as they navigate and choose which object to select. The amount of time they spend with their gaze on each object allows us to infer how close to optimal their attentional allocations are, so we can track the development of optimal attentional allocations through the course of the experiment. We will also be making sub-cranial ECOG recordings from a subset of our human participants, and multi-unit recordings from nonhuman primates performing the same task, which will enable us to investigate the neural correlates of this attentional learning.

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**Manipulating sensory mismatch in virtual reality through vestibular stimulation**

*Séamas Weech, Nikolaus F. Troje*

Simulator sickness in virtual reality (VR) poses a massive barrier to widespread adoption of current VR technologies. Galvanic vestibular stimulation (GVS) administered at the mastoid processes presents a potential technique for reducing simulator sickness during simulated motion. This benefit is thought to be achieved by reducing visual and vestibular mismatch, which is also thought to be associated with the degree of immersiveness and vection experienced. However, the invasiveness of GVS means it is unlikely to find widespread adoption as a remedy for simulator sickness. Here we examined whether noisy vestibular stimulation achieved through bone conducted vibration (BCV) of the vestibular system could facilitate vection and reduce simulator sickness in virtual reality. In Experiment 1 we presented a large-field optic flow stimulus and stimulated the vestibular system using BCV and noisy GVS at visual motion onset. The results suggest that BCV and GVS both caused participants to feel as if their body was in motion sooner than when vestibular stimulation was absent. In Experiment 2 we asked if reducing cue mismatch in VR can also help to prevent simulator sickness. Participants performed a spatial navigation task in an immersive virtual environment and responded to a simulator sickness questionnaire. In each trial, vestibular stimulation was either concurrent with large angular accelerations of the projection camera; applied randomly throughout each trial; or absent. Path navigation was controlled actively by participants using motion control, or was automated using pre-recorded motion trajectories. The results show that vestibular stimulation was associated with lower sickness when administered during active navigation, but only when the stimulation was concurrent with motion of the projection camera. The findings help to pave the way towards a non-invasive method that could improve immersiveness and diminish simulator sickness in VR.

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**Pupil dilation under a perceptual rivalry task as an indirect measurement of locus coeruleus activity in prodromal and manifest neurodegenerative diseases (e.g. Parkinson's disease)**

*Karén Wilhelm, Eva Picard, Christoph Best, Wolfgang Einhäuser-Treyer, and Wolfgang H. Oertel*

**Objective:** REM sleep behavior disorder (RBD) is a parasomnia which is defined by a loss of muscle atonia during REM sleep. Approximately 10 to 15 years after diagnosis about 85% of the patients with idiopathic RBD show a conversion to the alpha-synucleinopathy Parkinson's disease (PD), dementia with Lewy bodies (DLB) or to a much lesser extent to multiple system atrophy (MSA) - making this disease the most specific prodromal marker for PD. According to the Braak staging of PD the sleep-dream REM-parasomnia RBD represents Braak stage 2 to 3 in the development of PD. In those early stages of PD the noradrenergic locus coeruleus (LC) is already impaired. This anatomic structure in the brain stem modulates the autonomic nervous system by norepinephrine and seems especially involved in the control of muscle atonia during REM sleep. Further, the LC regulates attention and the orienting response. Hence, the noradrenergic LC is accepted to be involved in pupil dilation during cognitive and perceptual tasks.
**Method:** A non-invasive method to investigate the function of the noradrenergic LC is to detect pupil dilation by an eye-tracking-system under a perceptual rivalry task. The later provokes different internal percepts of the same visual stimulus. During the presentation of the so called Necker cube, we register visual perception changes by keypress and examine the associated pupil reaction as an indirect measurement of noradrenergic LC activation.
**Results:** So far, we examined differences in the pupillometric signal of N = 27 patients with RBD, N = 14 de novo PD, N = 26 patients with PD in def. OFF, N = 12 PD with dopaminergic medication, N = 8 patients with MSA, and N = 33 healthy controls. Pupil dilation and dominance duration was significantly diminished in iRBD-patients compared to healthy age matched controls ($p < .05$).
**Conclusion:** The reduced pupil dilation and less stable perception of the cube in patients with RBD support our hypothesis of a dysfunction of the LC in RBD. An impaired LC causes a reduced noradrenergic neurotransmission in the central nervous system and, therefore, to a limited pupil reaction under perceptual rivalry. The detailed data analysis is ongoing.
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**Effects of reward are caused by the necessity to choose**

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Humans can maximize reward by choosing the option with the largest expected value (reward probability × reward magnitude). Expected value has been shown to be negatively correlated with the latency of saccades to single targets (Milstein and Dorris, 2007). Here we show that this relationship only holds when responses to single targets are embedded in a context where participants additionally have to choose between different options. Participants were rewarded for saccades to targets appearing either left or right from fixation. In a trial, either one (single-trial) or two targets (choice-trial) were displayed. In choice-trials, participants had to decide for one of the two targets and received the corresponding reward. Within a block, one target always received a high, the other one a low reward. Across blocks, we varied the amount of choice trials within a block (0%, 25% or 75%) and the reward difference between the two targets (low or high difference). In single-trials, the effects of reward on saccade latencies were only present for blocks including choice-trials and increased with the amount of choice-trials within one block. When high and low rewards were inverted in single and choice-trials, latencies in single trials were actually shorter for lower rewarded targets. These results suggest that there is no direct connection between expected value and saccadic preparation. Rather it appears that the necessity to choose between high and low rewards leads to inhibition of the low-reward target and that only this inhibition is causing the reward effects in the latency of sensorimotor decisions such as saccades.

Milstein DM, Dorris MC (2007) The influence of expected value on saccadic preparation. J Neurosci 27:4810–4818.

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**Differential effects of HD-tDCS on mIPS and PMd in reach planning**

*Xu, S., Gallivan, J., and Blohm, G*

Reaching to a target requires a movement plan, i.e., a difference vector of the target position with respect to the initial hand position. While it is known that activity in the medial intraparietal sulcus (mIPS) and dorsal premotor (PMd) reflects aspects of a kinematic plan for a reaching movement, it is unclear how these regions may differ.

We investigated the functional roles of the left mIPS and PMd in the planning of reaching movements using high definition transcranial direct current stimulation (HD-tDCS) and examined changes in performance in response to stimulation at each site. The left mIPS and PMd were functionally localized (fMRI) and mapped onto the scalp (Brainsight). Anodal or cathodal stimulation (2mA for 20 min; 3cm radius; 4x1 electrode placement) was delivered on separate visits in a randomized, single-blind manner. Each participant performed 750 total (baseline, stimulation, post-stimulation) reaches starting from one of two IHPs to one of 4 briefly flashed targets (20 cm distant, 5 cm apart horizontally) while fixating on a straight-ahead cross on the target line.

Separate 2-way RM ANOVAs of the horizontal endpoint error difference revealed a significant IHP by target interaction effect after cathodal stimulation of the mIPS (IHP-dependent contraction), but only significant IHP and target main effects when applied at the PMd (movement vector modulated independently of IHP). This suggests that the movement vector is not yet formed at the input level of mIPS, but is encoded at the input of PMd. Furthermore, the relative effects of anodal and cathodal stimulation on reach amplitude differed across regions. Cathodal stimulation at the mIPS reduced amplitude compared to anodal stimulation but the reverse was true when applied at the PMd. This difference might be due to competitive vs non-competitive dynamics in PMd and mIPS respectively. In summary, we conclude that tDCS is a viable, useful method in investigating movement planning through temporary perturbations of the system.

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**Revising the concept of functional equivalence between motor imagery and execution via MVPA and RSA**

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Simulation theory proposes motor imagery (MI) to be a simulation based on representations also used for motor execution (ME). Nonetheless, it is unclear how far they use the same neural code. We use representational similarity analysis (RSA) to describe the neural representations associated with MI and ME within the fronto-parietal motor network. During fMRI-scanning, 20 volunteers imagined or executed three different types of right-hand actions. Results of RSA showed that RDMs (representational dissimilarity matrices) of frontal and parietal areas showed that MI and ME representations formed separate clusters, but that the representational organization of action types within these clusters was identical. For most ROIs, this pattern of results best fits with a model that assumes a low to moderate degree of similarity between the neural patterns associated with MI and ME. Thus, neural representations of MI and ME are neither the same nor totally distinct, but exhibit a similar structural geometry with respect to different types of action.

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