SENSORI-MOTOR CONTROL

Summary of research and teaching projects at the Institute of Physiology (Christian-Albrechts-Universität zu Kiel) :

1) Sensori-motor control in human subjects (=> see A-F on pages 2-8): Gait patterns and kinematics of walking have been studied in healthy volunteers and in different patient groups. Gait analysis is complemented with studies of the concomitant muscle activity, using electromyography (EMG) to describe arm, shoulder and trunk muscle activation patterns.

Prehension movements and grip forces of the human hand are another research issue. The effects of probabilistic visual cues indicating object weight on the scaling of grip forces have been outlined (Trampenau et al. 2015, 2017). Related investigations with Parkinsonian patients are under way (collaboration with Dept. of Neurology, UKSH Campus Kiel). The effects of visual illusions on grasping and on saccadic eye movements were analyzed to uncover relationships between perception and action. In collaboration the UKSH Campus Kiel (Neuroradiology), functional magnetic resonance imaging (fMRI) was used to study brain activation during various sensori-motor tasks. As an example, cortical activity during precision and power grip tasks was delineated (=> see D, page 4).

2) Studies with patients: Recovery of sensorimotor functions in children after traumatic brain injuries was studied in collaboration with the Neurologisches Rehabilitationszentrum Friedehorst (Bremen). In co-operation with the Departments of Neurology and Neuropediatrics (UKSH Campus Kiel), we analyzed the precision grip in children with cerebral palsy and myelomeningocele. EMG and gait studies were performed with parkinsonian patients, e.g., in camptocormia, which is a postural disorder characterized by pathological flexion of the trunk (=> see G, page 9).

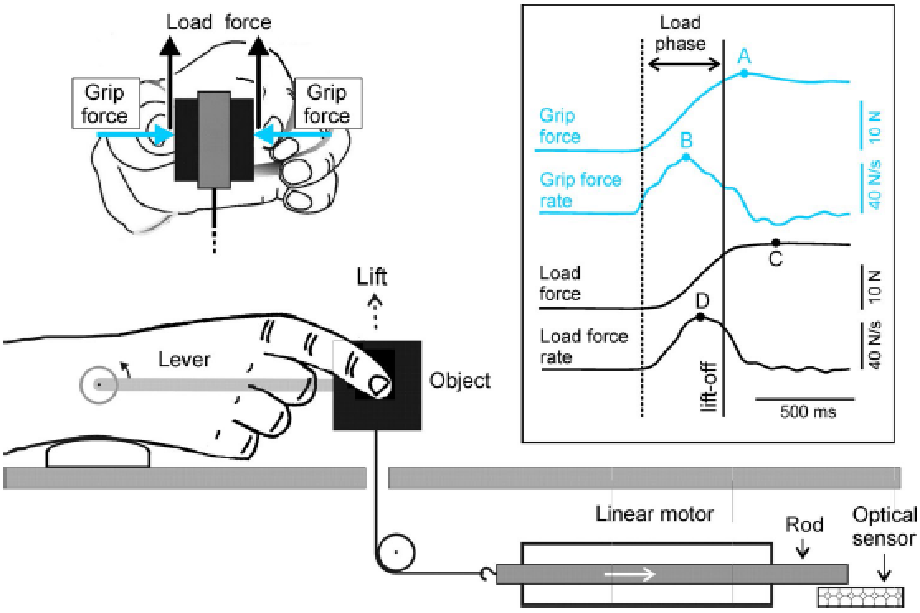
3) Sensori-motor control in animals: Spinal circuits (e.g. Renshaw inhibition, Ia interneurons) were studied with intra- and extracellular recordings of neuronal activity and histological methods. Locomotion and grasping movements were investigated in cats with quantitative kinematic X-ray techniques.

4) Teaching: Data of the thermal detection and pain thresholds have been collected and evaluated in the context of a laboratory exercise for undergraduate medical students. Video demonstrations of physiology experiments have been created for classroom use. Echocardiography has been introduced as part of student exercises. Classic German publications on the cardiac pressure-volume relationship and other issues of cardiophysiology have been translated and commented upon in collaboration with the International Institute for Theoretical Cardiology IIfTC, Prof. Dr. Jochen Schaefer (=> see H, I on pages 10-11).

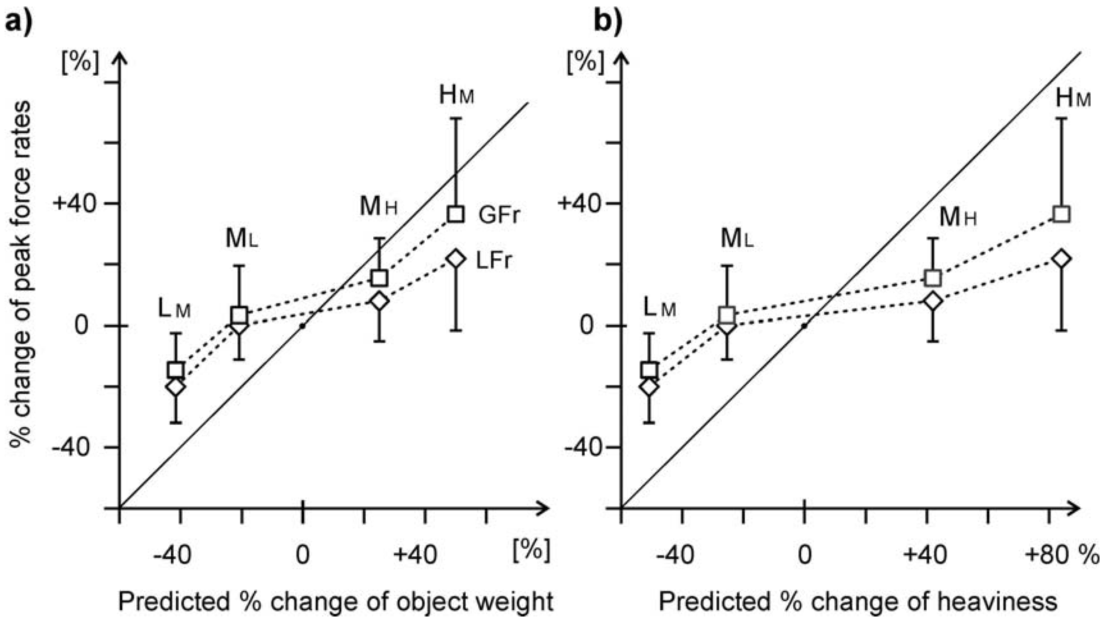
The following pages (2-11) present some projects in more detail.

(*updated 10’ 2018)*

A) GRIP FORCES ARE INFLUENCED BY PROBABILISTIC CUES

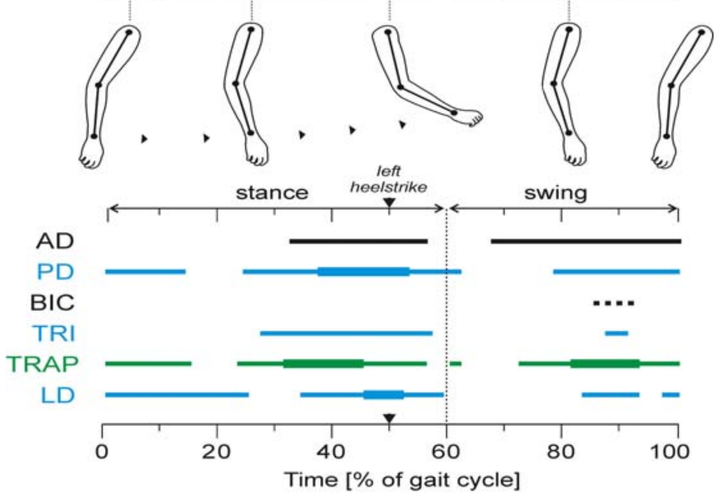


Healthy volunteers watched probabilistic cues that indicated the likely weight of an object that was grasped and lifted with the right hand (see figure above). The predictive scaling of the grip and lift forces prior to lift-off was influenced by these cues. However, the effects of probabilistic cues on force rates were nonlinear, since anticipatory adaptations of the motor output generally seemed to overestimate high probabilities and to underestimate low probabilities (see figure below). This trait of the motor system resembled the behaviour of a person who does not (or hardly) react when the weather forecast predicts 33 % chance of rain, but habitually puts on a raincoat when the predicted probability of rain is 66 %. For details see Trampenau et al. 2015, Exp Brain Res 233 (6); Trampenau et al. 2017, Atten Percept Psychophys 79.



B) ARM SWING DURING HUMAN GAIT and ASSOCIATED MUSCLE ACTIVITY

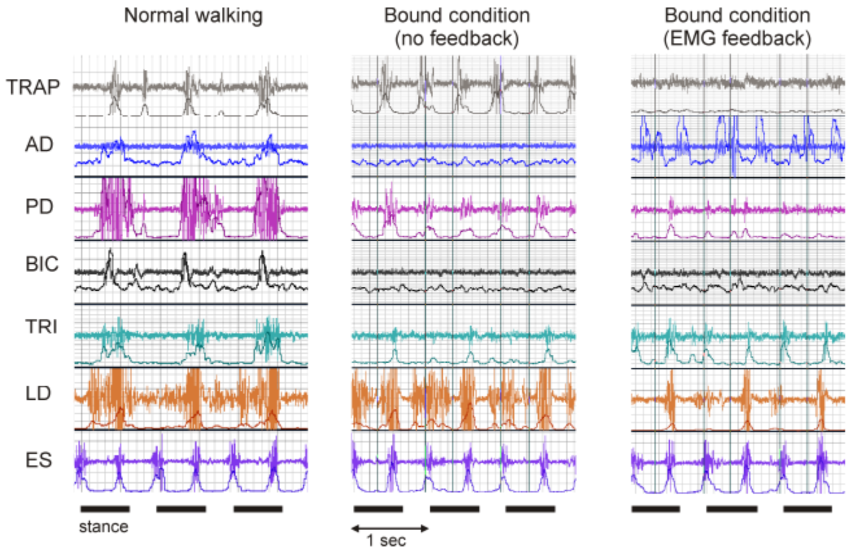
Kinematics and Electromyography (EMG)



Activity of flexor (black) and extensor (blue) muscles during treadmill walking.
AD, PD: anterior, posterior deltoid; BIC, TRI: biceps, triceps; TRAP: trapezius;
LD: latissimus dorsi

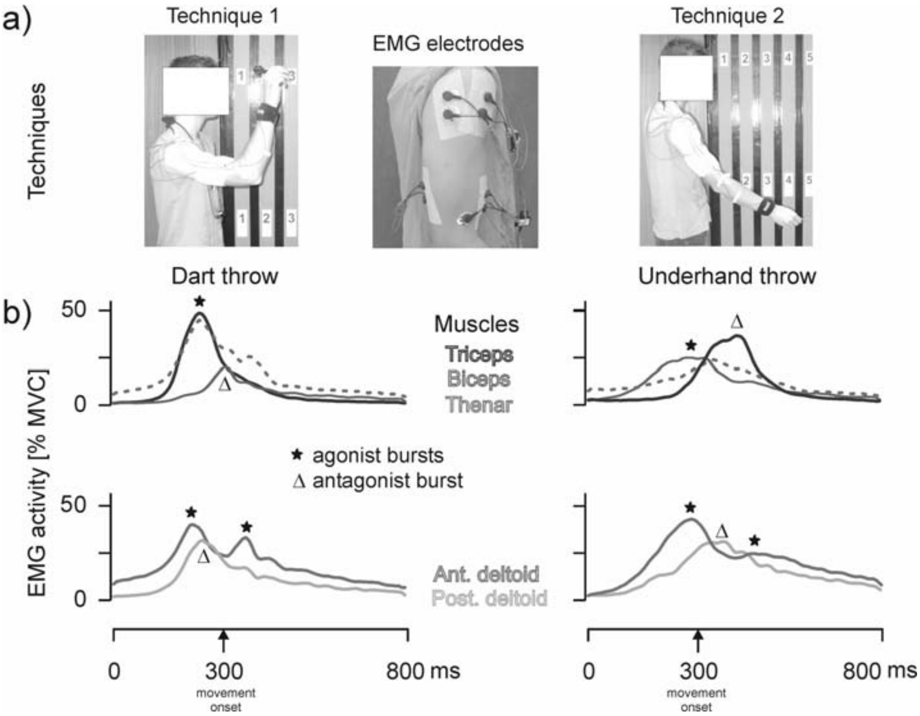
Arm swing is a typical feature of human walking, but little is known about the underlying motor control. Is it an active or a passive movement ? The kinematics of arm swing and the concomitant activity of arm and shoulder muscles were investigated in normal subjects during treadmill walking. Physiological asymmetries of arm swing kinematics were found. EMG signals of upper limb muscles indicated an, at least in part, active movement. The rhythmical muscle activity persisted to some extent even when the arms were immobilized during walking (Bound condition, see figure below), suggesting the influence of a central motor pattern that coupled leg and arm muscle activations. For details see, e.g., Kuhtz-Buschbeck, Frendel, Jing (2014) “Arm Swing during Human Gait Studied by EMG of Upper Limb Muscles”, in “Applications, Challenges, and Advancements in Electromyography Signal Processing” Editor: G Naik. IGI Global, Hershey, PA, USA.

EMG of arm and shoulder muscles during walking with immobilized arms

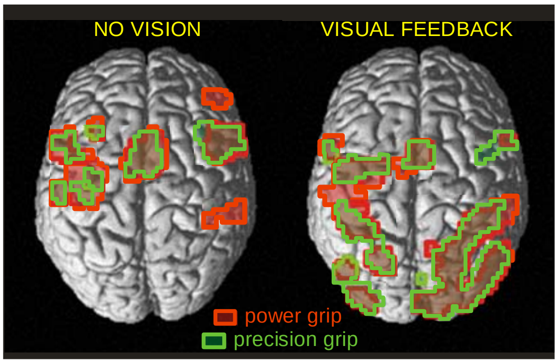


C) HANDEDNESS AND THROWING MOVEMENTS : AN EMG STUDY

Throwing movements are more accurate when performed with the dominant arm, as compared to the non-dominant arm. In an EMG study of aimed throwing in normal volunteers we found interlimb differences in the timing of activation of an antagonist muscle: The onset of the EMG burst of the posterior deltoid muscle was delayed by ~20-30 ms on the non-dominant side during two throwing techniques. Otherwise the EMG curves of dominant and non-dominant arm muscles were very similar, which supports the concept of motor equivalence. It means that about the same movement can be performed by different effectors (limbs or muscle groups), as specified by a superordinate motor program (ongoing project; P. Keller & J.P. Kuhtz-Buschbeck).



D) BRAIN ACTIVITY DURING PRECISION AND POWER GRIP TASKS

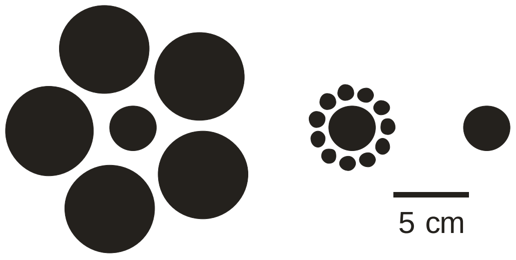


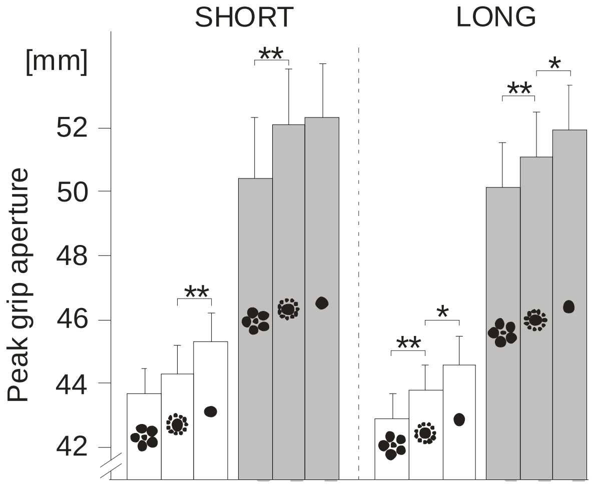
Using functional magnetic resonance imaging (fMRI), we compared brain activity of normal volunteers during rhythmical power and precision grip tasks of the dominant right hand. The grip forces were matched. Visual feedback of the force curves was either provided (right panel) or lacking (left panel). There was a high overlap of the regions engaged in both precision gripping (green) and power gripping (red), see Kuhtz-Buschbeck et al. (2008), NeuroImage 40.

E) PERCEPTION AND ACTION : GRASPING AND WATCHING VISUAL ILLUSIONS

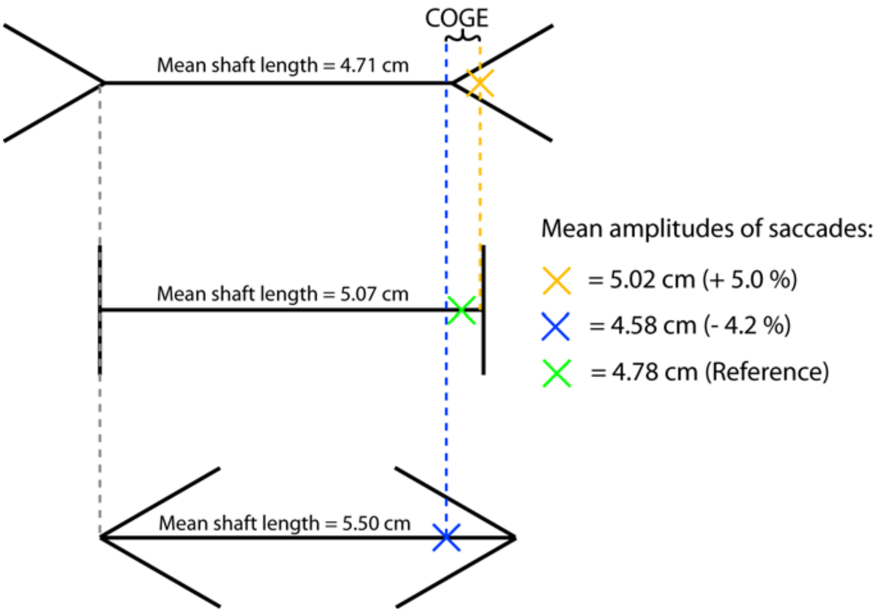
Effects of visual illusions on perception were compared with their effects on action to investigate whether perception and action systems use different codes (two-visual-systems hypothesis) or common codes. The assumption that the Ebbinghaus illusion (upper left figure) deceives perception but not grasping (action) would be in line with two-visual-systems hypothesis. However, we found differences of the grip apertures when subjects grasped the central disc of the illusion. The presence of flankers per se caused a general reduction of the grip aperture. In another study, saccades were carried out along adjusted Müller-Lyer figures (lower figure), which were perceptually equivalent. Nevertheless the saccades had different amplitudes, indicating a ‘center of gravity effect’, which had to be corrected for. The results are in agreement with a common internal representation for perception and action. For details see Gilster et al. (2006), Experimental Brain Research 171; Gilster & Kuhtz-Buschbeck (2011), Journal of Vision 10.

Grasping :





Saccades :

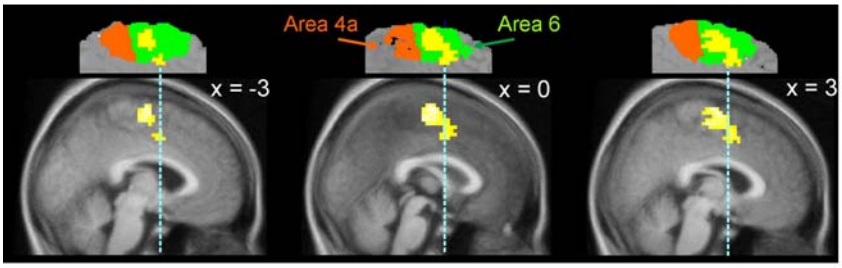


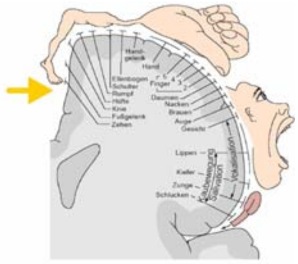
F) MOTOR CORTICAL REPRESENTATION OF PELVIC FLOOR MUSCLES

This is supplementary material of the publication
Schrum A, Wolff S, van der Horst C, Kuhtz-Buschbeck JP. Motor cortical representation of the pelvic floor muscles. J Urol. 2011 Jul;186(1): 185-90.

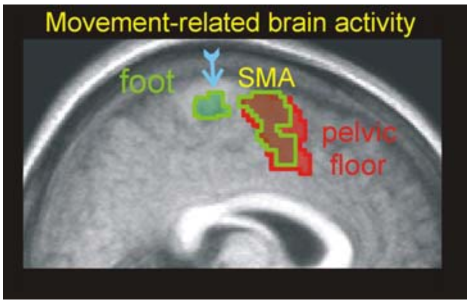
To delineate the representation of pelvic floor muscles, fMRI experiments were carried out with thirty healthy subjects (15 women, 15 men), who performed rhythmical (1Hz) pelvic floor muscle contractions. Consistent activity of the medial wall was found. The figures below show the group result with mid- and parasagittal slices. Active regions are indicated yellow. The regions of the primary motor cortex (red, Area 4a) and supplementary motor area SMA (green, Area 6) are shown, based on cytoarchitectonic probability maps (see Eickhoff et al., Neuroimage 25, 2005). For details see Kuhtz-Buschbeck et al. (2007), Neuroimage 35.

Hence, the main motor representation of the pelvic floor seems to be located medially in the cortex lining the interhemispheric fissure (mainly SMA), and <u>not</u> at the margo superior cerebri (Mantelkante) of the precentral gyrus.



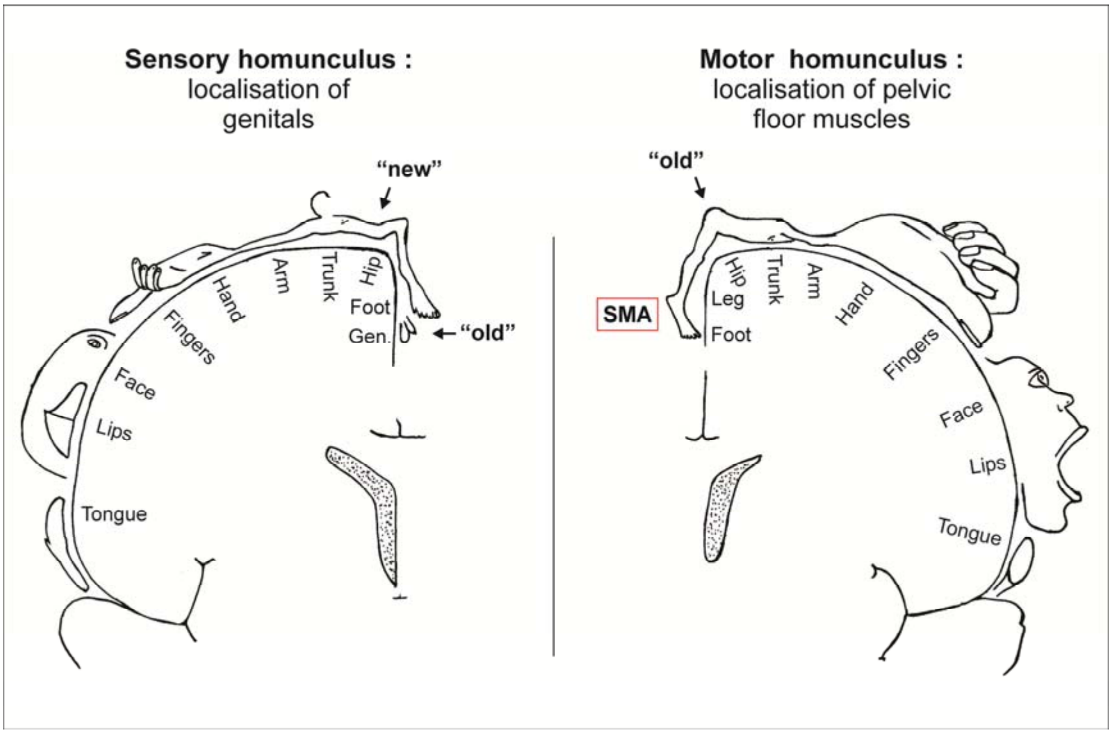


Further fMRI experiments compared the motor representations of pelvic floor and toes. 17 male volunteers performed voluntary contractions of pelvic floor muscles, and toe movements as a control task. Strongly overlapping activity was found in the medial wall (see figure below: pelvic floor [red] and foot/toes [green]), again mainly in the SMA according to cytoarchitectonic probability maps. Activity of the paracentral lobule (medial primary motor cortex, blue arrow) was stronger during toe movements than during pelvic floor contractions; in the latter task, signals of this region did not reach significance.



These results confirm the strong motor representation of the pelvic floor in the medial wall (SMA). This differs from the well-known ‘classical’ motor homunculus figure. Interestingly, concerning the ‘classical’ sensory homunculus, neuroimaging data published by others (Kell et al. 2005, Michels et al. 2010) suggest a “shift” of the sensory representation of the genitals from the medial to the superolateral postcentral gyrus.

The drawings below show the ‘classical’ somatosensory (left) and motor (right) homunculi, as they appear in many textbooks. They are adapted from the well known figures published by Penfield and Rasmussen (The cerebral cortex of man. 1950. New York: Macmillan).



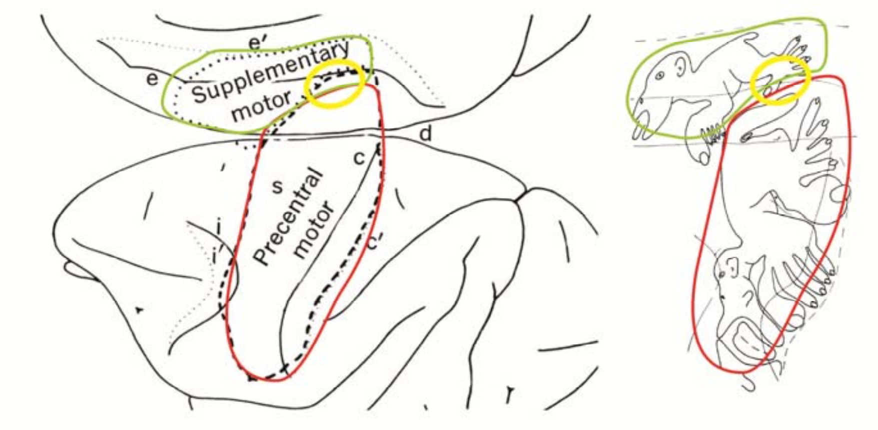
Sensory homunculus: “old” indicates the sensory representation of genitals according to the classic homunculus figure. “new” indicates their representation in superolateral postcentral gyrus according to two neuroimaging studies, namely:

- Kell CA et al. : The sensory cortical representation of the human penis: revisiting somatotopy in the male homunculus. J Neurosci 2005; 25: 5984.
- Michels L et al. : The somatosensory representation of the human clitoris: an fMRI study. Neuroimage 2010; 49: 177.

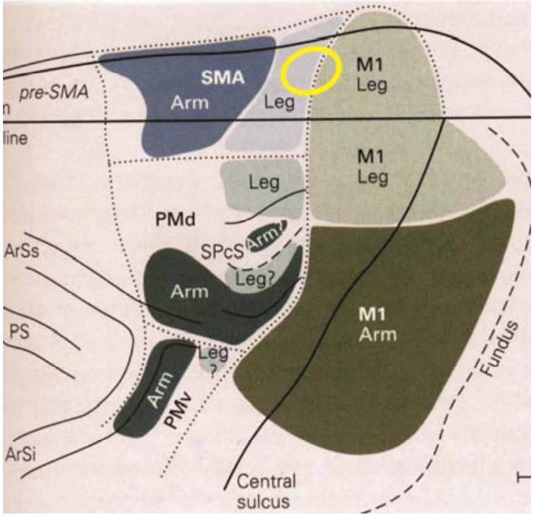
Motor homunculus: “old” indicates the motor representation of the pelvic floor in the precentral gyrus near the margo superior cerebri (Mantelkante) according to the classic figure. “SMA” indicates the predominant representation of pelvic floor muscles in the supplementary motor area [Brodmann Area 6]. Predominant SMA activity during pelvic floor contractions was found in the following neuroimaging studies :

- Kuhtz-Buschbeck JP et al. : Activation of the supplementary motor area (SMA) during voluntary pelvic floor muscle contractions -- an fMRI study. Neuroimage 2007; 35: 449.
- Zhang H et al. : An fMRI study of the role of suprapontine brain structures in the voluntary voiding control induced by pelvic floor contraction. Neuroimage 2005; 24: 174.
- Schrum et al. : Motor cortical representation of the pelvic floor muscles. Journal of Urology 2011; 186: 185.

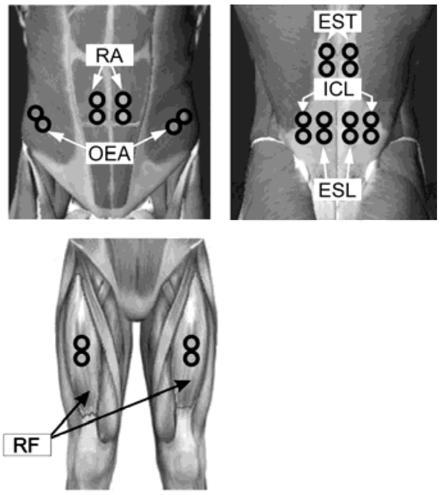
Taken together, fMRI data indicate a conspicuous motor representation of the pelvic floor in the SMA. There may also be a representation in the medial primary motor cortex, involving the border region between SMA and primary motor cortex. The boundary between the primary motor cortex and the SMA varies inter-individually; it is not abrupt and not always at the same stereotaxic coordinates (see Eickhoff et al., Neuroimage 25, 2005). Studies of non-human primates (electrical cortical stimulation) reported two motor representations of the entire body (two simiusculi), one in the SMA and another one in the primary motor cortex (see figures below). The hindlimb / tail regions of both simiusculi lie adjacent to each other in the border region (yellow), where the cortical neurons innervating motor nuclei of pelvic floor muscles might be located.

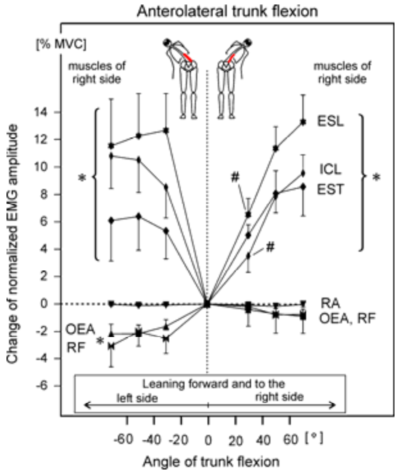


Figures adapted from Woolsey et al.: Focal cortical electrical stimulation in monkeys A. Res. Nerv. Ment Dis. 1952: 30. Somatotopic organisation of the motor cortices (precentral M1, supplementary SMA) in the monkey.
Yellow: border region with putative motor representation of the pelvic floor.

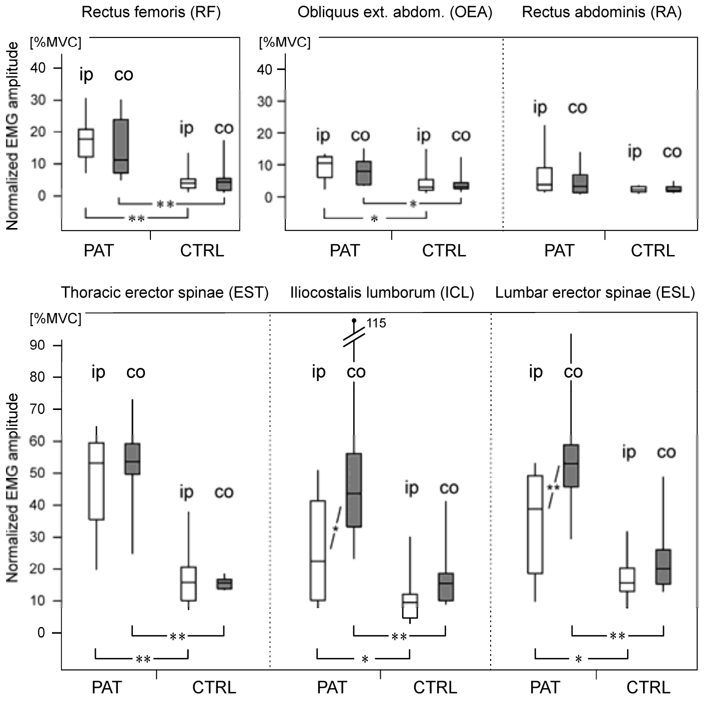


G) CAMPTOCORMIA in PARKINSONIAN PATIENTS

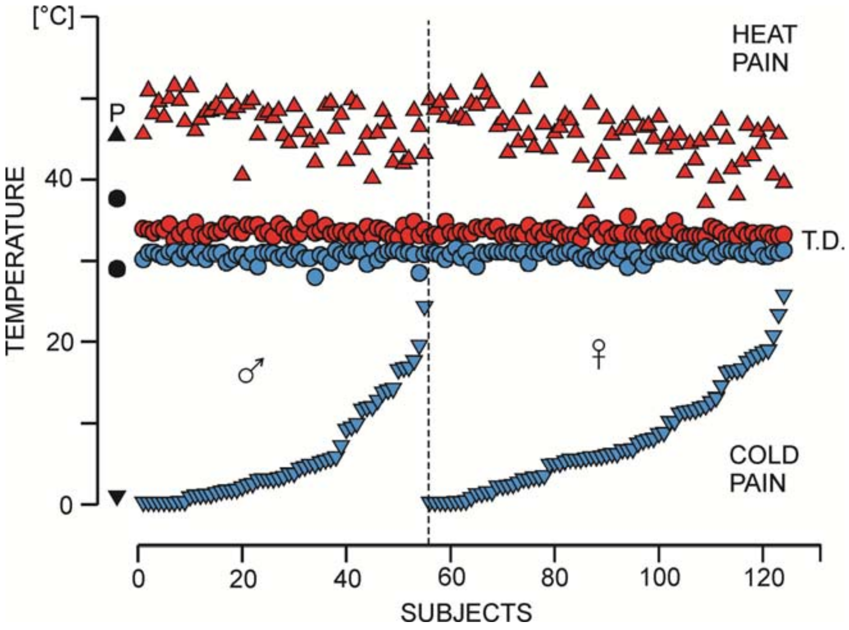




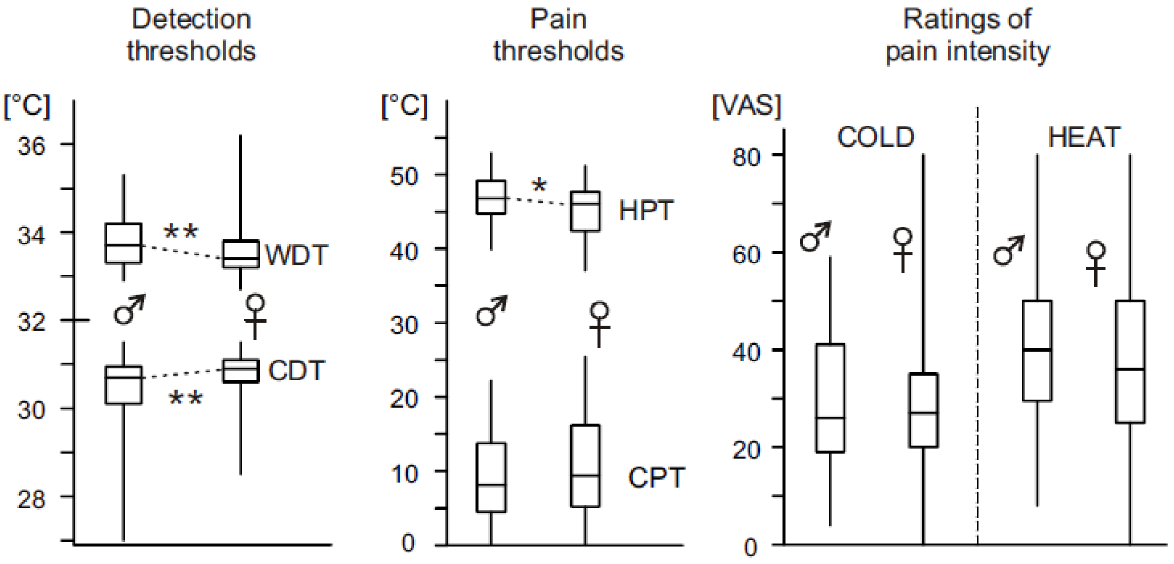
Camptocormia, frequently seen in Parkinson's disease (PD), is a pathological forward or anterolateral bending of the trunk that occurs while the patients stand or walk. To characterize relevant trunk muscle activity, electromyographic (EMG) recordings were performed in PD patients with camptocormia and in controls. Increasing forward trunk flexion (while standing) was associated with increasing erector spinae muscle activity in controls, whereas abdominal muscle activity was negligible. During anterolateral trunk flexion, back muscle activity increased particularly on the contralateral side. The patients showed a similar pattern. However, EMG activity of their trunk extensors was significantly higher than in controls, often reaching half-maximal amplitudes. PD patients with camptocormia therefore must use the functional reserve of their erector spinae muscles to counteract gravity in the attempt to maintain an upright posture. This indicates a pathological weakness of paravertebral muscles. The study was a collaboration between the Institute of Physiology and the Department of Neurology, UKSH Campus Kiel. For details see Margraf, Rogalski, Deuschl, Kuhtz-Buschbeck (2017), Parkinsonism and Related Disorders 44, 44-50.



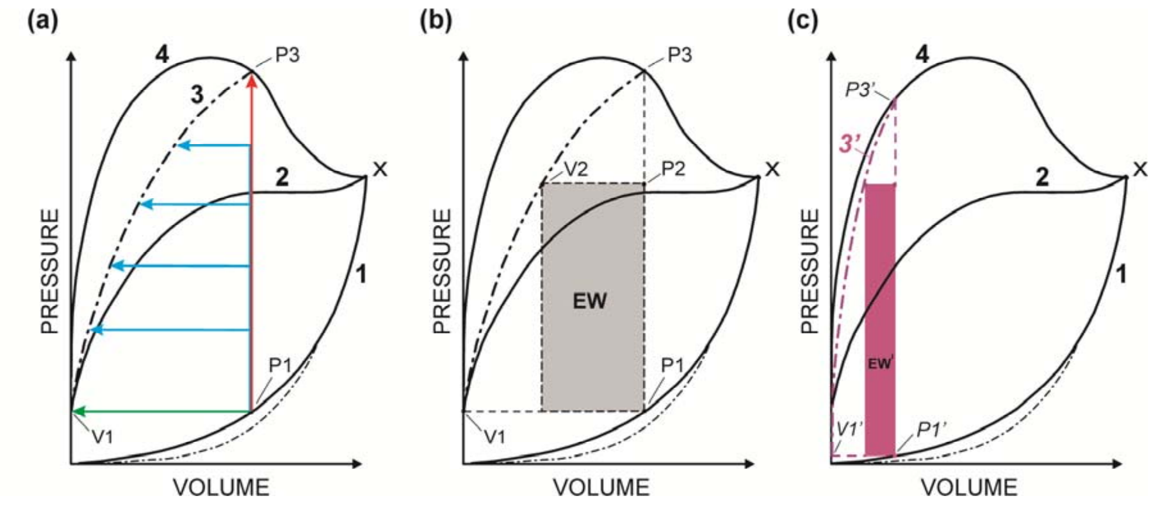
H) TEACHING: ANALYSES OF THERMAL SENSITIVITY



Data of thermal detection and thermal pain thresholds (heat pain, cold pain; triangles) at the thenar of the right hand were collected from ~300 persons during a student laboratory exercise. Women detected warm and cold stimuli more sensitively than men and had lower heat pain thresholds. Habituation gradually shifted the pain thresholds during repeated testing. The cold pain threshold was lower when tested after heat pain than in the reverse case (order effect). Ratings of pain intensity correlated with the threshold temperature for heat pain, but not for cold pain. Subjects with a high threshold for heat pain tended to be insensitive for cold pain as well. Normal values of the warm (WDT) and cold (CDT) detection thresholds and the heat (HPT) and cold (CPT) pain thresholds were published. The top figure also shows exemplary data of a neuropathy patient with less sensitive detection thresholds (subject P, black symbols). For details see Kuhtz-Buschbeck, Göbel, Andresen, Stick (2010), Advances in Physiology Education 34, 25-34.



I) CLASSIC PAPERS ON CARDIAC PHYSIOLOGY



Classic papers on cardiac mechanics form a basis of modern teaching concepts. In the late 19th century, the German physiologist Otto Frank (1865–1944) laid down the mathematical, methodological, and theoretical foundations to understand the performance of the heart and circulatory system. The existence of the “Frank-Starling law” testifies to this. Frank’s pressure-volume diagram of the frog heart is still shown, yet often with alterations, in textbooks of physiology. In collaboration with the IIfTC (International Institute for Theoretical Cardiology), we compared Ernest Starling’s “Law of the Heart” (1918) with the mathematically based view of cardiac mechanics put forward by Otto Frank earlier (1897). Frank’s diagrams gained influence in German cardio-physiological publications, but they were widely unknown abroad until 1969, when Hiroyuki Suga began to present similar approaches for warm-blooded animals as Frank had done for the frog. Suga succeeded in correlating the pressure volume area (PVA)—a composite of Frank’s work loop plus the area of remaining potential energy—with the oxygen consumption of the beating heart. For details see Kuhtz-Buschbeck, Lie, Schaefer, Wilder (2016): Reassessing Diagrams of Cardiac Mechanics, Perspectives in Biology and Medicine (59)4: 471–490.

The influence of Otto Frank’s research can still be seen in modern cardiology and cardio-physiology, such as in the development of modern interactive simulating and teaching programs. We have translated ten of Frank’s core papers to English and commented them. The articles show a wealth of theoretical assumptions and projections regarding the importance of the sarcomere, the development of models of contraction, thermo-dynamical considerations for muscular activity, differences between cardiac and skeletal muscles, problems related to methodology and measurement, and the first pressure-volume diagram of the frog heart. For the translations (open access) and Frank’s original papers see Kuhtz-Buschbeck, Drake-Holland, Noble, Lohff, Schaefer (2018), Rediscovery of Otto Frank’s contribution to science, Journal of Molecular and Cellular Cardiology 119.

DISSERTATIONS (“Doktorarbeiten”, in German, since 2000)

Jörn Schattschneider (2000) : Greif- und Zielbewegungen bei Katzen mit Läsionen des dorsolateralen Funikulus – eine röntgenkinematische Studie.
(Forelimb movements in cats with lesions of the cervical spinal cord)

Hilka Maria Drücke (2001) : Quantitative Ganganalyse bei Patienten mit Morbus Parkinson und Normaldruckhydrozephalus.
(Comparative gait analyses in patients with Parkinson’s disease and hydrocephalus; see publication #33, below)

Silke Andrea Mäder (2002) : Ganganalyse bei Patienten mit zervikaler Myelopathie.
(Pre- and postoperative gait analyses in patients with lesions of the cervical spinal cord; see publication #26, below)

Ulf Laubinger (2002) : Optoelektronische Vermessung der Ziel- und Greifbewegung bei vier- bis zwölfjährigen Kindern und Vergleich mit motometrischen Tests.
(The development of grasping and gross motor functions in normal children; see publications #20 and #25 below)

Christof van der Horst (2003) : Laufbandlokomotion und das Gehen über Grund. Ein Vergleich von Schrittparametern bei Kindern und Erwachsenen.
(This thesis compares overground walking with gait on a treadmill in adults and children; see publication #18 below)

Monika Pötter (2003) : Präsynaptische Hemmung an der vorderen Extremität der Katze - Kontrolle und Steuerung durch segmentale und descendierende Systeme.
(Presynaptic inhibition in the spinal circuitry of motorneurons and interneurons steering the forelimb of the cat)

Jan Herzog (2003) : Prämotorische Interneurone im zervikalen Rückenmark der Katze. Untersuchungen mittels an Lektin gebundene Meerrettich-Peroxidase.
(Motor neurons and interneurons of the cat spinal cord studied by trans-synaptic labeling with horseradish peroxidase; see publication #32 below)

Birgit Hoppe (2003) : Restitution sensomotorischer Funktionen nach Schädel-Hirn-Trauma bei Kindern.
(Restitution of hand motor functions and neuropsychological functions in children after traumatic brain injuries; see publication #40 below)

Alexandra Grosskopf (2004) : Kinematische Analyse von Ziel- und Greifbewegungen der dominanten und non-dominanten Hand bei beiden Geschlechtern. Diss. Mat. Nat. Fakultät (Anthropologie).
(Prehension movements of the left and right hand have been analysed and compared; see publication #45 below)

Rene Gilster (2004) : Dissoziation von visuellen Subsystemen ? Eine Studie über den Einfluss der Titchener-Illusion auf das Greifen nach Objekten unter Berücksichtigung von visuellem Feedback und der Präsentationsdauer.
Diplomarbeit; Inst. für Psychologie, in Zusammenarbeit mit der Physiologie.
(The influence of a visual illusion on grasping has been characterized by kinematic analyses; see publication #46 below)

Inga Schinkel (2005) : Entwicklung des Gangbildes bei Kindern.
(Normal gait development in children described with quantitative parameters)

Marina Müller (2005) : Restitution sensomotorischer Funktionen bei Kindern nach Schädel-Hirn-Trauma: Analysen des Präzisionsgriffs.
(Fingertip forces of the precision grip in children after traumatic brain injuries; see publication #41 below)

Ute Damm-Stünitz (2005) : Ganganalyse bei Kindern und Jugendlichen im Verlauf der Rehabilitation nach Schädel-Hirn-Trauma.
(The recovery of walking in children after traumatic brain injuries; see publication #40 below)

Annika B. Liersch (2006) : Etablierung eines Parkinson-Tiermodells durch die Applikation des Meperidine-Analogons MPTP in der Katze. Eine kinematische, biochemische und verhaltensbiologische Studie.
(An animal model of Parkinson’s disease in the cat by application of MPTP)

Markus Armin Holzhäuser (2006) : Optoelektronische Analyse gezielter Greifbewegungen bei Kindern und Jugendlichen nach Schädel-Hirn-Trauma.
(Quantitative kinematic analyses of reach-to-grasp movements in children after traumatic brain injuries)

Christina Pott (2006) : Kortikale Kontrolle der Perzeption von Harndrang.
(Cortical control of the pelvic floor and the perception of bladder fullness, see publication #44 below)

Christian Mahnkopf (2007) : Hirnaktivität bei einfachen und komplexen Fingerbewegungen: Eine funktionelle Magnetresonanz-Tomographie Studie.
(Brain activity during executed and imagined hand movements, see publication #39 below)

Christine Barbara Schütz (2007) : Untersuchung des Präzisionsgriffs bei Patienten mit Meningomyelozele.
(Control of precision grip forces in children with spina bifida, see publication #37 below)

Caroline Maria Krüger (2008) : Laufbandtraining bei Kindern mit Cerebralparese. (Treadmill training in children with cerebral palsy)

René Gilster (2008) : Theoretische und experimentelle Untersuchung über den Zusammenhang von Perzeption und Handlung. Diss. Philosophische Fakultät (Psychologie).
(Mechanisms of perception and action were investigated by studies of saccadic eye movements and of prehension movements, using visual illusions, see publications #46 and #54 below)

Katja Brockmann (2010) : Der Armschwung beim Gehen.
(Kinematics of arm swing during treadmill walking, see publication #48 below).

Wiebke Andresen (2010): Quantitative sensorische Testung des Temperaturempfindens bei gesunden Probanden: Analyse von Normwerten und Betrachtungen zur Methodik.
(Thermoreception and nociception of the skin, see publication #53 below).

Bo Jing (2011): Der Armschwung beim Gehen und Laufen: Elektromyographische Untersuchung von Probanden.
(Upper limb muscle activity during human walking, see publication #56 below)

Stephan Bruno Göbel (2013): Quantitative sensorische Testung des Temperaturempfindens verschiedener Körperregionen.
(Thermoreception and nociception in different skin regions of the human body, see publication #53).

Lars Nöhden (2016): Kortikale Repräsentationen der Beckenboden- und Beinmuskulatur – eine fMRT – Studie.
(Cortical representations of pelvic floor and leg muscles studied with fMRI).

Antonia Frendel (2016): Aktivität von Schulter- und Rumpfmuskeln unter verschiedenen Bedingungen des menschlichen Gehens.
(Shoulder and trunk muscle activity in different walking conditions, see publications #59, 60, 83 below).

SELECTED PUBLICATIONS

1) Alstermark, B., Isa, T., Kümmel, H., Tantisera, B. (1990) Projection from excitatory C3-C4 propriospinal neurones to lamina VII and VIII neurones in the C6-Th1 segments of the cat. Neuroscience Research 8: 1-7.

2) Alstermark, B., Kümmel, H. (1990) Transneuronal transport of wheat germ agglutinin conjugated horseradish peroxidase into last order spinal interneurones projecting to acromio- and spinodeltoideus motoneurones in the cat. 1. Location of labelled interneurones and influence of synaptic activity on the transneuronal transport. Experimental Brain Research 80: 83-95.

3) Alstermark, B., Kümmel, H. (1990) Transneuronal transport of wheat germ agglutinin conjugated horseradish peroxidase into last order spinal interneurones projecting to acromio- and spinodeltoideus motoneurones in the cat. 2. Differential labelling of interneurones depending on movement type. Experimental Brain Research 80: 96-103.

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