PASIG PERFORMING ARTS
SPECIAL INTEREST GROUP

ORTHOPAEDIC SECTION
AMERICAN PHYSICAL THERAPY ASSOCIATION

APTA
American Physical Therapy Association
The Science of Healing. The Art of Caring.

PASIG MONTHLY CITATION BLAST: No.46 **Nov – Dec 2009**

Dear PASIG members:

It's time to plan to attend Combined Sections Meeting 2010. We're excited to announce our PASIG Programming:

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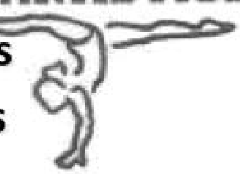
Physical Therapy Management in GYMNASTICS



Spine, Shoulder, Wrist, Hand Injuries coupled with Stress and Eating Disorders

A Performing Arts PT Challenge

Introduction to Pathology Related to the Sport of Gymnastics: Epidemiology and Evaluative Screening
Mark D. Sleeper, PT, MS, OCS

Rhythmic Gymnastics and Spine Injury
Elizabeth Ann Darling, PT, MPT, OCS, ATC

Injuries of the Shoulder, Wrist and Hand-Clinical Pearls
Julie Ann Guthrie, PT, DPT, OCS

Gymnastics Rehabilitation and Progressions
Airelle Hunter Giordano PT, DPT, OCS, SCS

Saturday February 20, 2009
8am-11am

CSM San Diego, CA

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The PASIG Business meeting precedes our programming at 7am. Yes, CSM will meet during the Olympics (2.12 – 2.28.10). I hope to watch some of it with PASIG friends and colleagues who may shine some insight into the new scoring system for ice skating.

In January, our BLAST topic will reflect our gymnastics programming. We will also provide you with a list of new performing arts research as well as related platforms and posters that may be of interest to our members.

For this combined November – December Citation BLAST, I've selected the topic: *Motor Imagery for Enhanced Movement Execution.* The format is an annotated bibliography of articles on the selected topic from 1998 – 2008. The BLASTS and updated libraries are posted on the PASIG webpage for our members to access and download. (Information about EndNote referencing software can be found at http://www.endnote.com, including a 30-day free trial).

If you are interested in contributing a special topic citation blast, please contact me. As always, your comments and suggestions are welcome. Please drop me an e-mail anytime. If you're seeking a research mentor, looking for a sounding board about a research idea, want some editorial suggestions on a manuscript, let me know and I'll try to connect you with the right researcher.

Hope to see you at CSM,
Shaw

Shaw Bronner PT, PhD, OCS
Chair, PASIG Research Committee
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Motor Imagery for Enhanced Movement Execution

Students often are interested in conducting research on the effectiveness of imagery to change motor control. I question them on what they know about imagery, what they think may be the neural correlates of imagined practice v. motor practice. It turns out that they aren't very familiar with the imaging literature related to this topic. I thought this might be of general interest to the performing arts community because imagery is often used in dance and other performance pedagogy.

Mental rehearsal has long been familiar to athletes and musicians as a partial substitute for physical practice. Behavioral improvements such as improved speed, strength, and performance accuracy have been reported when physical practice is augmented with mental rehearsal. Motor imagery most commonly has two modes: visual motor imagery (VMI) and kinesthetic motor imagery (KMI). VMI involves imagining seeing yourself performing a movement. KMI involves imagining the feeling of performing a certain movement.

If motor imagery and motor performance are related phenomena, then they should share the same neural mechanisms. Is imagery the same as the physical movement itself? The answer is maybe.

Experiments with implanted electrodes into the motor cortex of the brain to activate a robotic or paralyzed limb demonstrate the potential of imagery. Advances in non-invasive techniques for studying brain activity, including EEG, PET, and MRI during physical and mental practice, show some interesting similarities and differences between the two. Areas in the frontal lobes that support planning, and the parietal lobes that support spatial representations and working memory, tend to be active equally during physical and mental practice. The evidence is more mixed about primary motor cortex (M1), which exerts direct control over voluntary muscle movement. Some studies find no involvement of M1 during mental rehearsal, while others reported activation. Other studies found activation of the cerebellum with physical practice but none with mental practice. Recent application of near-infrared spectroscopy (NIRS), which is temporally more accurate than fMRI, found temporal differences between imagined and physical movement.

Finally, imaging ability differs among individuals. Several rating scales have been developed to assess this ability, including the *Movement Imagery Questionnaire*, *Vividness of Motor Imagery Questionnaire*, and *Kinesthetic and Visual Imagery Questionnaire*. The level of training also seems to affect how imagery is used: skilled performers, with well-established motor representations of an activity, seem to activate motor areas, while novices activate visual areas.

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Aleman A, Nieuwenstein MR, et al. (2000). Music training and mental imagery ability. Neuropsychologia **38**(12): 1664-8.

Neuroimaging studies have suggested that the auditory cortex is involved in music processing as well as in auditory imagery. We hypothesized that music training may be associated with improved auditory imagery ability. In this study, performance of musically trained and musically naive subjects was compared on: (1) a musical mental imagery task (in which subjects had to mentally compare pitches of notes corresponding to lyrics taken from familiar songs); (2) a non-musical auditory imagery task (in which subjects had to mentally compare the acoustic characteristics of everyday sounds); and (3) a comparable measure of visual imagery (in which subjects had to mentally compare visual forms of objects). The musically trained group did not only perform better on the musical imagery task, but also outperformed musically naive subjects on the non-musical auditory imagery task. In contrast, the two groups did not differ on the visual imagery task. This finding is discussed in relation to theoretical proposals about music processing and brain activity.

Allami N, Paulignan Y, et al. (2008). Visuo-motor learning with combination of different rates of motor imagery and physical practice. Exp Brain Res **184**(1): 105-13.

Sports psychology suggests that mental rehearsal facilitates physical practice in athletes and clinical rehabilitation attempts to use mental rehearsal to restore motor function in hemiplegic patients. Our aim was to examine whether mental rehearsal is equivalent to physical learning, and to determine the optimal proportions of real execution and rehearsal. Subjects were asked to grasp an object and insert it into an adapted slot. One group (G0) practiced the task only by physical execution (240 trials); three groups imagined performing the task in different rates of trials (25%, G25; 50%, G50; 75%, G75), and physically executed movements for the remaining trials; a fourth, control group imagined a visual rotation task in 75% of the trials and then performed the same motor task as the others groups. Movement time (MT) was compared for the first and last physical trials, together with other key trials, across groups. All groups learned, suggesting that mental rehearsal is equivalent to physical motor learning. More importantly, when subjects rehearsed the task for large numbers of trials (G50 and G75), the MT of the first executed trial was significantly shorter than the first executed trial in the physical group (G0), indicating that mental practice is better than no practice at all. Comparison of the first executed trial in G25, G50 and G75 with the corresponding trials in G0 (61, 121 and 181 trials), showed equivalence between mental and physical practice. At the end of training, the performance was much better with high rates of mental practice (G50/G75) compared to physical practice alone (G0), especially when the task was difficult. These findings confirm that mental rehearsal can be beneficial for motor learning and suggest that imagery might be used to supplement or partly replace physical practice in clinical rehabilitation.

Bakker M, Overeem S, et al. (2008). Motor imagery of foot dorsiflexion and gait: effects on corticospinal excitability. Clin Neurophysiol **119**(11): 2519-27.

OBJECTIVE: We examined how corticospinal excitability was affected by motor imagery of foot dorsiflexion and motor imagery of gait. METHODS: Transcranial magnetic stimulation was applied over the primary motor cortex of 16 young healthy subjects while they performed imaginary foot dorsiflexions (Experiment I) and imaginary walking (Experiment II). Motor-evoked potentials (MEPs) were recorded from the tibialis anterior (TA) and first dorsal interosseus (FDI). MEPs recorded during motor imagery were compared to those recorded during a matched visual imagery task. RESULTS: Imagined foot dorsiflexions increased MEP areas in both TA and FDI. The increase in TA was stronger than in FDI. Overall, imagined walking did not change MEP areas. However, subjects with larger increases in TA during imagined foot dorsiflexion also showed larger increases in TA during imagined walking. CONCLUSIONS: Imagined foot dorsiflexions increase corticospinal excitability in both a task-related muscle (TA) and a task-unrelated muscle (FDI), with larger increases in the task-related muscle. Imagined gait only increases corticospinal excitability in those subjects with the largest increments during imagined foot dorsiflexion. SIGNIFICANCE: Imagery of a simple lower extremity movement evokes increases in corticospinal excitability. Furthermore, corticospinal effects of a simple motor imagery task can predict corticospinal effects of a more complex motor imagery task involving the same muscle.

Caldara R, Deiber MP, et al. (2004). Actual and mental motor preparation and execution: a spatiotemporal ERP study. Exp Brain Res **159**(3): 389-99.

Studies evaluating the role of the executive motor system in motor imagery came to a general agreement in favour of the activation of the primary motor area (M1) during imagery, although in reduced proportion as compared to motor execution. It is still unclear whether this difference occurs within the preparation period or the execution period of the movement, or both. In the present study, EEG was used to investigate separately the preparation and the execution periods of overt and covert movements in adults. We designed a paradigm that randomly mixed actual and kinaesthetic imagined trials of an externally paced sequence

of finger key presses. Sixty channel event-related potentials were recorded to capture the cerebral activations underlying the preparation for motor execution and motor imagery, as well as cerebral activations implied in motor execution and motor imagery. Classical waveform analysis was combined with data-driven spatiotemporal segmentation analysis. In addition, a LAURA source localization algorithm was applied to functionally define brain related motor areas. Our results showed first that the difference between actual and mental motor acts takes place at the late stage of the preparation period and consists of a quantitative modulation of the activity of common structures in M1. Second, they showed that primary motor structures are involved to the same extent in the actual or imagined execution of a motor act. These findings reinforce and refine the functional equivalence hypothesis between actual and imagined motor acts.

Carrillo-de-la-Pena MT, Galdo-Alvarez S, et al. (2008). Equivalent is not equal: primary motor cortex (MI) activation during motor imagery and execution of sequential movements. Brain Res **1226**: 134-43.

The motor hierarchy hypothesis and the related debate about the role of the primary motor cortex (MI) in motor preparation are major topics in cognitive neuroscience today. The present study combines the two strategies that have been followed to clarify the role of MI in motor preparation independently from execution: motor imagery and the use of precueing tasks. Event-related potentials (ERPs) were recorded while subjects either performed or just imagined sequential finger movements in response to a central target (numbers 1, 2 or 3) which was precued by arrows (at both sides of the screen) that provided information about response side. Both motor imagery and execution elicited Lateralized Readiness Potentials (LRPs) with similar morphology and latency. Given that the LRP is generated in MI, the results show that the primary motor cortex is also active during imagery and give support for the hypothesis of a functional equivalence between motor imagery and execution. Nevertheless, the analysis of the different moments of motor preparation (precue vs. target-induced activity) revealed important differences between both conditions: whereas there were no differences in LRPs nor in brain areas estimated by standardized low resolution tomographies (sLORETA) related to precue presentation, larger LRP amplitudes and higher activation of MI were found during motor execution than imagery in the target-related activity. These results have important implications for the development of brain-computer devices and for the use of motor imagery in neurorehabilitation.

Debarnot U, Creveaux T, et al. (2009). Sleep-related improvements in motor learning following mental practice. Brain Cogn **69**(2): 398-405.

A wide range of experimental studies have provided evidence that a night of sleep may enhance motor performance following physical practice (PP), but little is known, however, about its effect after motor imagery (MI). Using an explicitly learned pointing task paradigm, thirty participants were assigned to one of three groups that differed in the training method (PP, MI, and control groups). The physical performance was measured before training (pre-test), as well as before (post-test 1) and after a night of sleep (post-test 2). The time taken to complete the pointing tasks, the number of errors and the kinematic trajectories were the dependent variables. As expected, both the PP and the MI groups improved their performance during the post-test 1. The MI group was further found to enhance motor performance after sleep, hence suggesting that sleep-related effects are effective following mental practice. Such findings highlight the reliability of MI in learning process, which is thought consolidated when associated with sleep.

Decety J, Perani D, et al. (1994). Mapping motor representations with positron emission tomography. Nature **371**(6498): 600-2.

Brain activity was mapped in normal subjects during passive observation of the movements of an 'alien' hand and while imagining grasping objects with their own hand. None of the tasks required actual movement. Shifting from one mental task to the other greatly changed the pattern of brain activation. During observation of hand movements, activation was mainly found in visual cortical areas, but also in subcortical areas involved in motor behaviour, such as the basal ganglia and the cerebellum. During motor imagery, cortical and subcortical areas related to motor preparation and programming were strongly activated. These data support the notion that motor learning during observation of movements and mental practice involves rehearsal of neural pathways related to cognitive stages of motor control.

Dickstein R, Deutsch JE (2007). Motor imagery in physical therapist practice. Phys Ther **87**(7): 942-53.

Motor imagery is the mental representation of movement without any body movement. Abundant evidence on the positive effects of motor imagery practice on motor performance and learning in athletes, people who are healthy, and people with neurological conditions (eg, stroke, spinal cord injury, Parkinson disease) has been published. The purpose of this update is to synthesize the relevant literature about motor imagery in order to facilitate its integration into physical therapist practice. This update also will discuss visual and kinesthetic motor imagery, factors that modify motor imagery practice, the design of motor imagery protocols, and potential applications of motor imagery.

Dickstein R, Gazit-Grunwald M, et al. (2005). EMG activity in selected target muscles during imagery rising on tiptoes in healthy adults and poststroke hemiparetic patients. J Mot Behav **37**(6): 475-83.

The authors sought to gain further knowledge about activation of target muscles during imagery engagement in a motor task. Six hemiparetic patients and 9 healthy participants performed 3 real rises on tiptoes and then, after pausing, 3 imagery rises on tiptoes. Metronome beats guided the rate of rises and descents. Electromyographic (EMG) activity from the medial gastrocnemius and the rectus femoris muscles were monitored bilaterally throughout the performance of both tasks. In 3 healthy participants and 3 individuals with hemiparesis, EMG activity was related to the imagery task in at least 1 of the target muscles. Conversely, in the other participants, motor imagery practice was not accompanied by task-related EMG activity in the monitored muscles. In all cases, the increment in activation level during motor imagery practice was very low in comparison with that of real performance. The findings were not unequivocal; therefore, EMG activity may sometimes, but not always, be recorded during motor imagery practice both in healthy individuals and in poststroke hemiparetic participants. Further research is needed to align motor imagery practice with the objectives of motor rehabilitation.

Ehrsson HH, Geyer S, et al. (2003). Imagery of voluntary movement of fingers, toes, and tongue activates corresponding body-part-specific motor representations. J Neurophysiol **90**(5): 3304-16.

We investigate whether imagery of voluntary movements of different body parts activates somatotopical sections of the human motor cortices. We used functional magnetic resonance imaging to detect the cortical activity when 7 healthy subjects imagine performing repetitive (0.5-Hz) flexion/extension movements of the right fingers or right toes, or horizontal movements of the tongue. We also collected functional images when the subjects actually executed these movements and used these data to define somatotopical representations in the motor areas. In this study, we relate the functional activation maps to cytoarchitectural population maps of areas 4a, 4p, and 6 in the same standard anatomical

space. The important novel findings are 1). that imagery of hand movements specifically activates the hand sections of the contralateral primary motor cortex (area 4a) and the contralateral dorsal premotor cortex (area 6) and a hand representation located in the caudal cingulate motor area and the most ventral part of the supplementary motor area; 2). that when imagining making foot movements, the foot zones of the posterior part of the contralateral supplementary motor area (area 6) and the contralateral primary motor cortex (area 4a) are active; and 3). that imagery of tongue movements activates the tongue region of the primary motor cortex and the premotor cortex bilaterally (areas 4a, 4p, and 6). These results demonstrate that imagery of action engages the somatotopically organized sections of the primary motor cortex in a systematic manner as well as activating some body-part-specific representations in the nonprimary motor areas. Thus the content of the mental motor image, in this case the body part, is reflected in the pattern of motor cortical activation.

Fontani G, Migliorini S, et al. (2007). Effect of mental imagery on the development of skilled motor actions. Percept Mot Skills 105(3 Pt 1): 803-26.

To test the effect of imagery in the training of skilled movements, an experiment was designed in which athletes learned a new motor action and trained themselves for a month either by overt action or by mental imagery of the action. The experiment was carried out with 30 male karateka (M age = 35 yr., SD = 8.7; M years of practice = 6, SD = 3) instructed to perform an action (Ura-Shuto-Uchi) that they had not previously learned. The athletes were divided into three groups: Untrained (10 subjects who did not perform any training), Action Trained (10 subjects who performed Ura-Shuto-Uchi training daily for 16 minutes), and Mental Imagery (10 subjects who performed mental imagery training of Ura-Shuto-Uchi daily for 16 minutes). The subjects were tested five times, once every 7 days. During each test, they performed a series of 60 motor action trials. In Tests 1, 3, and 5, they also performed a series of 60 mental imagery trials. During the trials, an electroencephalogram (EEG), electromyography (EMG), muscle strength and power, and other physiological parameters were recorded. The results differed by group. Untrained subjects did not show significant effects. In the Action Trained group, training had an effect on reactivity and movement speed, with a reduction of EMG activation and reaction times. Moreover, muscle strength, power, and work increased significantly. The Mental Imagery group showed the same effects on muscle strength, power, and work, but changes in reactivity were not observed. In the Mental Imagery group, the study of Movement Related Brain Macropotentials indicated a progressive modification of the profile of the waves from Test 1 to Test 5 during imagery, showing significant variations of the amplitude of the waves related to the premotor and motor execution periods. Results show that motor imagery can influence muscular abilities such as strength and power and can modify Movement Related Brain Macropotentials, the profile of which potentially could be used to verify the effectiveness of motor imagery training.

Fourkas AD, Bonavolonta V, et al. (2008). Kinesthetic imagery and tool-specific modulation of corticospinal representations in expert tennis players. Cereb Cortex **18**(10): 2382-90.

Specific physical or mental practice may induce short- and long-term neuroplastic changes in the motor system and cause tools to become part of one's own body representation. Athletes who use tools as part of their practice may be an excellent model for assessing the neural correlates of possible bodily representation changes that are specific to extensive practice. We used single-pulse transcranial magnetic stimulation to measure corticospinal excitability in forearm and hand muscles of expert tennis players and novices while they mentally practiced a tennis forehand, table tennis forehand, and a golf drive. The muscles of expert tennis players showed increased corticospinal facilitation during motor imagery of tennis but not golf or table tennis. Novices, although athletes, were not modulated across

sports. Subjective reports indicated that only in the tennis imagery condition did experts differ from novices in the ability to form proprioceptive images and to consider the tool as an extension of the hand. Neurophysiological and subjective data converge to suggest a key role of long-term experience in modulating sensorimotor body representations during mental simulation of sports.

Gabbard C, Ammar D, et al. (2009). Testing the distinctiveness of visual imagery and motor imagery in a reach paradigm. Int J Neurosci **119**(3): 353-65.

We examined the distinctiveness of motor imagery (MI) and visual imagery (VI) in the context of perceived reachability. The aim was to explore the notion that the two visual modes have distinctive processing properties tied to the two-visual-system hypothesis. The experiment included an interference tactic whereby participants completed two tasks at the same time: a visual or motor-interference task combined with a MI or VI-reaching task. We expected increased error would occur when the imaged task and the interference task were matched (e.g., MI with the motor task), suggesting an association based on the assumption that the two tasks were in competition for space on the same processing pathway. Alternatively, if there were no differences, dissociation could be inferred. Significant increases in the number of errors were found when the modalities for the imaged (both MI and VI) task and the interference task were matched. Therefore, it appears that MI and VI in the context of perceived reachability recruit different processing mechanisms.

Gentili R, Papaxanthis C, et al. (2006). Improvement and generalization of arm motor performance through motor imagery practice. Neuroscience **137**(3): 761-72.

This study compares the improvement and generalization of arm motor performance after physical or mental training in a motor task requiring a speed-accuracy tradeoff. During the pre- and post-training sessions, 40 subjects pointed with their right arm as accurately and as fast as possible toward targets placed in the frontal plane. Arm movements were performed in two different workspaces called right and left paths. During the training sessions, which included only the right path, subjects were divided into four training groups (n = 10): (i) the physical group, subjects overtly performed the task; (ii) the mental group, subjects imagined themselves performing the task; (iii) the active control group, subjects performed eye movements through the targets, (iv) the passive control group, subjects did not receive any specific training. We recorded movement duration, peak acceleration and electromyographic signals from arm muscles. Our findings showed that after both physical and mental training on the right path (training path), hand movement duration and peak acceleration respectively decreased and increased for this path. However, motor performance improvement was greater after physical compared with mental practice. Interestingly, we also observed a partial learning generalization, namely an enhancement of motor performance for the left path (non-training path). The amount of this generalization was roughly similar for the physical and mental groups. Furthermore, while arm muscle activity progressively increased during the training period for the physical group, the activity of the same muscles for the mental group was unchanged and comparable with that of the rest condition. Control groups did not exhibit any improvement. These findings put forward the idea that mental training facilitates motor learning and allows its partial transfer to nearby workspaces. They further suggest that motor prediction, a common process during both actual and imagined movements, is a fundamental operation for both sensorimotor control and learning.

Golomer E, Bouillette A, et al. (2008). Effects of mental imagery styles on shoulder and hip rotations during preparation of pirouettes. J Mot Behav **40**(4): 281-90.

To analyze individual behavior in spatial navigation especially for pirouette preparations (complete whole-body rotations), the authors studied horizontal shoulder-hip interactions under 2 constraints: postural (right and left supporting legs [SL]) and spatial (clockwise [CW] and counterclockwise [CCW]). They performed kinematic analysis at the start and end of the shoulder-hip horizontal rotations (run-up) with regard to imagery of motor actions. On the basis of the Vividness of Movement Imagery Questionnaire, they classified 8 female expert ballet dancers and 7 untrained female participants according to their movement imagery style (kinesthetic and visual). At the run-up's end, the shoulders initiated the turn independently of SL but differently depending on training: CW for dancers and CCW for untrained participants (their commonly used direction). Kinesthetic and mixed imagery styles prevailed in dancers, whereas simply a mixed style appeared among untrained participants. Thus, dance training enhances the imagery of kinesthetic sensation and influences the choice of spatial direction, facilitating the body-space interaction.

Guillot A, Collet C, et al. (2008). Functional neuroanatomical networks associated with expertise in motor imagery. Neuroimage **41**(4): 1471-83.

Although numerous behavioural studies provide evidence that there exist wide differences within individual motor imagery (MI) abilities, little is known with regards to the functional neuroanatomical networks that dissociate someone with good versus poor MI capacities. For the first time, we thus compared, through functional magnetic resonance imaging (fMRI), the pattern of cerebral activations in 13 skilled and 15 unskilled imagers during both physical execution and MI of a sequence of finger movements. Differences in MI abilities were assessed using well-established questionnaire and chronometric measures, as well as a new index based upon the subject's peripheral responses from the autonomic nervous system. As expected, both good and poor imagers activated the inferior and superior parietal lobules, as well as motor-related regions including the lateral and medial premotor cortex, the cerebellum and putamen. Inter-group comparisons revealed that good imagers activated more the parietal and ventrolateral premotor regions, which are known to play a critical role in the generation of mental images. By contrast, poor imagers recruited the cerebellum, orbito-frontal and posterior cingulate cortices. Consistent with findings from the motor sequence learning literature and Doyon and Ungerleider's model of motor learning [Doyon, J., Ungerleider, L.G., 2002. Functional anatomy of motor skill learning. In: Squire, L.R., Schacter, D.L. (Eds.), Neuropsychology of memory, Guilford Press, pp. 225-238], our results demonstrate that compared to skilled imagers, poor imagers not only need to recruit the cortico-striatal system, but to compensate with the cortico-cerebellar system during MI of sequential movements.

Guillot A, Collet C, et al. (2009). Brain activity during visual versus kinesthetic imagery: an fMRI study. Hum Brain Mapp **30**(7): 2157-72.

Although there is ample evidence that motor imagery activates similar cerebral regions to those solicited during actual movements, it is still unknown whether visual (VI) and kinesthetic imagery (KI) recruit comparable or distinct neural networks. The present study was thus designed to identify, through functional magnetic resonance imaging at 3.0 Tesla in 13 skilled imagers, the cerebral structures implicated in VI and KI. Participants were scanned in a perceptual control condition and while physically executing or focusing during motor imagery on either the visual or kinesthetic components of an explicitly known sequence of finger movements. Subjects' imagery abilities were assessed using well-established psychological, chronometric, and new physiological measures from the autonomic nervous system. Compared with the perceptual condition, physical executing, VI, and KI resulted in overlapping (albeit non-identical) brain activations, including motor-related regions and the inferior and superior parietal lobules. By contrast, a divergent pattern of

increased activity was observed when VI and KI were compared directly: VI activated predominantly the occipital regions and the superior parietal lobules, whereas KI yielded more activity in motor-associated structures and the inferior parietal lobule. These results suggest that VI and KI are mediated through separate neural systems, which contribute differently during processes of motor learning and neurological rehabilitation.

Hanakawa T, Dimyan MA, et al. (2008). Motor planning, imagery, and execution in the distributed motor network: a time-course study with functional MRI. Cereb Cortex **18**(12): 2775-88.

Activation of motor-related areas has consistently been found during various motor imagery tasks and is regarded as the central mechanism generating motor imagery. However, the extent to which motor execution and imagery share neural substrates remains controversial. We examined brain activity during preparation for and execution of physical or mental finger tapping. During a functional magnetic resonance imaging at 3 T, 13 healthy volunteers performed an instructed delay finger-tapping task either in a physical mode or mental mode. Number stimuli instructed subjects about a finger-tapping sequence. After an instructed delay period, cue stimuli prompted them either to execute the tapping movement or to imagine it. Two types of planning/preparatory activity common for movement and imagery were found: instruction stimulus-related activity represented widely in multiple motor-related areas and delay period activity in the medial frontal areas. Although brain activity during movement execution and imagery was largely shared in the distributed motor network, imagery-related activity was in general more closely related to instruction-related activity than to the motor execution-related activity. Specifically, activity in the medial superior frontal gyrus, anterior cingulate cortex, precentral sulcus, supramarginal gyrus, fusiform gyrus, and posterolateral cerebellum likely reflects willed generation of virtual motor commands and analysis of virtual sensory signals.

Hanakawa T, Immisch I, et al. (2003). Functional properties of brain areas associated with motor execution and imagery. J Neurophysiol **89**(2): 989-1002.

Imagining motor acts is a cognitive task that engages parts of the executive motor system. While motor imagery has been intensively studied using neuroimaging techniques, most studies lack behavioral observations. Here, we used functional MRI to compare the functional neuroanatomy of motor execution and imagery using a task that objectively assesses imagery performance. With surface electromyographic monitoring within a scanner, 10 healthy subjects performed sequential finger-tapping movements according to visually presented number stimuli in either a movement or an imagery mode of performance. We also examined effects of varied and fixed stimulus types that differ in stimulus dependency of the task. Statistical parametric mapping revealed movement-predominant activity, imagery-predominant activity, and activity common to both movement and imagery modes of performance (movement-and-imagery activity). The movement-predominant activity included the primary sensory and motor areas, parietal operculum, and anterior cerebellum that had little imagery-related activity (-0.1 ~ 0.1%), and the caudal premotor areas and area 5 that had mild-to-moderate imagery-related activity (0.2 ~ 0.7%). Many frontoparietal areas and posterior cerebellum demonstrated movement-and-imagery activity. Imagery-predominant areas included the precentral sulcus at the level of middle frontal gyrus and the posterior superior parietal cortex/precuneus. Moreover, activity of the superior precentral sulcus and intraparietal sulcus areas, predominantly on the left, was associated with accuracy of the imagery task performance. Activity of the inferior precentral sulcus (area 6/44) showed stimulus-type effect particularly for the imagery mode. A time-course analysis of activity suggested a functional gradient, which was characterized by a more "executive" or more "imaginative" property in many areas related to movement and/or imagery. The results from the present study provide new insights into the functional neuroanatomy of motor imagery, including the effects of imagery performance and stimulus-dependency on brain activity.

Herholz SC, Lappe C, et al. (2008). Neural basis of music imagery and the effect of musical expertise. Eur J Neurosci **28**(11): 2352-60.

Although the influence of long-term musical training on the processing of heard music has been the subject of many studies, the neural basis of music imagery and the effect of musical expertise remain insufficiently understood. By means of magnetoencephalography (MEG) we compared musicians and nonmusicians in a musical imagery task with familiar melodies. Subjects listened to the beginnings of the melodies, continued them in their imagination and then heard a tone which was either a correct or an incorrect further continuation of the melody. Only in musicians was the imagery of these melodies strong enough to elicit an early preattentive brain response to unexpected incorrect continuations of the imagined melodies; this response, the imagery mismatch negativity (iMMN), peaked approximately 175 ms after tone onset and was right-lateralized. In contrast to previous studies the iMMN was not based on a heard but on a purely imagined memory trace. Our results suggest that in trained musicians imagery and perception rely on similar neuronal correlates, and that the musicians' intense musical training has modified this network to achieve a superior ability for imagery and preattentive processing of music.

Higuchi S, Imamizu H, et al. (2007). Cerebellar activity evoked by common tool-use execution and imagery tasks: an fMRI study. Cortex **43**(3): 350-8.

The purpose of this study is to identify the functional brain networks activated in relation to actual tool-use in humans. Although previous studies have identified brain activity related to tool-use gestures (Moll et al., 2000), they did not investigate the brain activity involved in such tool-use. We investigated brain activity using functional magnetic resonance imaging (fMRI) while human subjects mentally imagined using sixteen common tools and while they actually used them. Brain activity for both actual and imagined tool-use was found in the posterior part of the parietal cortex, in the supplementary motor area, and in the cerebellum. Under imagined tool-use conditions, we found brain activity in the premotor and right pars opercularis. Under actual tool-use conditions, we found it in the primary motor area, in the thalamus, and in the left pars opercularis. Our precise analysis in the cerebellum indicated that activity evoked by imagery was located significantly more lateral to that evoked by actual use. We found a relationship between activity in the tool imagery and execution conditions by comparing their t-value-weighted centroid of activation coordinates. Moreover, for half of the subjects the spatial distribution pattern for each tool was similar, suggesting that neural mechanisms contributing to skillful tool-use are modularly organized in the cerebellum.

Jackson PL, Lafleur MF, et al. (2003). Functional cerebral reorganization following motor sequence learning through mental practice with motor imagery. Neuroimage **20**(2): 1171-80.

The goal of the present study was to examine, via positron emission tomography, the functional changes associated with the learning of a sequence of foot movements through mental practice with motor imagery (MI). Following intensive MI training over several days, which led to a modest but significant improvement in performance, healthy subjects showed an increase in activity restricted to the medial aspect of the orbitofrontal cortex (OFC), and a decrease in the cerebellum. These main results are largely consistent with those found in a previous study of sequence learning performed in our laboratory after physical practice of the same task [NeuroImage 16 (2002) 142]. Further analyses showed a positive correlation between the blood flow increase in the OFC and the percentage of improvement on the foot sequence task. Moreover, the increased involvement of the medial OFC revealed a modality specific anatomo-functional organization, as imagination of the sequential task after MI practice activated a more posterior region than its execution. These results demonstrate that learning a sequential motor task through motor imagery practice produces cerebral functional changes similar to those observed after physical practice of the same task. Moreover, the findings are in accord with the hypothesis that mental practice with MI, at least initially, improves performance by acting on the preparation and anticipation of movements rather than on execution per se.

Lafleur MF, Jackson PL, et al. (2002). Motor learning produces parallel dynamic functional changes during the execution and imagination of sequential foot movements. Neuroimage **16**(1): 142-57.

The aim of the present positron emission tomography study was to measure the dynamic changes in cerebral activity before and after practice of an explicitly known sequence of foot movements when executed physically and to compare them to those elicited during motor imagery of the same movements. Nine healthy volunteers were scanned while performing both types of movement at an early phase of learning and after a 1-h training period of a sequence of dorsiflexions and plantarflexions with the left foot. These experimental conditions were compared directly, as well as to a perceptual control condition. Changes in regional cerebral blood flow associated with physical execution of the sequence early in the learning process were observed bilaterally in the dorsal premotor cortex and cerebellum, as well as in the left inferior parietal lobule. After training, however, most of these brain regions were no longer significantly activated, suggesting that they are critical for establishing the cognitive strategies and motor routines involved in executing sequential foot movements. By contrast, after practice, an increased level of activity was seen bilaterally in the medial orbitofrontal cortex and striatum, as well as in the left rostral portion of the anterior cingulate and a different region of the inferior parietal lobule, suggesting that these structures play an important role in the development of a long lasting representation of the sequence. Finally, as predicted, a similar pattern of dynamic changes was observed in both phases of learning during the motor imagery conditions. This last finding suggests that the cerebral plasticity occurring during the incremental acquisition of a motor sequence executed physically is reflected by the covert production of this skilled behavior using motor imagery.

Meister IG, Krings T, et al. (2004). Playing piano in the mind--an fMRI study on music imagery and performance in pianists. Brain Res Cogn Brain Res **19**(3): 219-28.

Reading of musical notes and playing piano is a very complex motor task which requires years of practice. In addition to motor skills, rapid and effective visuomotor transformation as well as processing of the different components of music like pitch, rhythm and musical texture are involved. The aim of the present study was the investigation of the cortical network which mediates music performance compared to music imagery in 12 music academy students playing the right hand part of a Bartok piece using functional magnetic resonance imaging (fMRI). In both conditions, fMRI activations of a bilateral frontoparietal network comprising the premotor areas, the precuneus and the medial part of Brodmann Area 40 were found. During music performance but not during imagery the contralateral primary motor cortex and posterior parietal cortex (PPC) bilaterally was active. This reflects the role of primary motor cortex for motor execution but not imagery and the higher visuomotor integration requirements during music performance compared to simulation. The notion that the same areas are involved in visuomotor transformation/motor planning and music processing emphasizes the multimodal properties of cortical areas involved in music and motor imagery in musicians.

Milton J, Small SL, et al. (2008). Imaging motor imagery: methodological issues related to expertise. Methods **45**(4): 336-41.
Mental imagery (MI) is the mental rehearsal of movements without overt execution. Brain imaging techniques have made it possible to identify the brain regions that are activated during MI and, for voluntary motor tasks involving hand and finger movements, to make direct comparison with those areas activated during actual movement. However, the fact that brain activation differs for different types of imagery (visual or kinetic) and depends on the skill level of the individual (e.g., novice or elite athlete) raises a number of important methodological issues for the design of brain imaging protocols to study MI. These include instructing the subject concerning the type of imagery to use, objective measurement of skill level, the design of motor tasks sufficiently difficult to produce a range of skill levels, the effect of different environments on skill level (including the imaging device), and so on. It is suggested that MI is more about the neurobiology of the development of motor skills that have already been learned, but not perfected, than it is about learning motor skills de novo.

Munzert J, Zentgraf K, et al. (2008). Neural activation in cognitive motor processes: comparing motor imagery and observation of gymnastic movements. Exp Brain Res **188**(3): 437-44.
The simulation concept suggested by Jeannerod (Neuroimage 14:S103-S109, 2001) defines the S-states of action observation and mental simulation of action as action-related mental states lacking overt execution. Within this framework, similarities and neural overlap between S-states and overt execution are interpreted as providing the common basis for the motor representations implemented within the motor system. The present brain imaging study compared activation overlap and differential activation during mental simulation (motor imagery) with that while observing gymnastic movements. The fMRI conjunction analysis revealed overlapping activation for both S-states in primary motor cortex, premotor cortex, and the supplementary motor area as well as in the intraparietal sulcus, cerebellar hemispheres, and parts of the basal ganglia. A direct contrast between the motor imagery and observation conditions revealed stronger activation for imagery in the posterior insula and the anterior cingulate gyrus. The hippocampus, the superior parietal lobe, and the cerebellar areas were differentially activated in the observation condition. In general, these data corroborate the concept of action-related S-states because of the high overlap in core motor as well as in motor-related areas. We argue that differential activity between S-states relates to task-specific and modal information processing.

Nair DG, Purcott KL, et al. (2003). Cortical and cerebellar activity of the human brain during imagined and executed unimanual and bimanual action sequences: a functional MRI study. Brain Res Cogn Brain Res **15**(3): 250-60.
The neural (blood oxygenation level dependent) correlates of executed and imagined finger sequences, both unimanual and bimanual, were studied in adult right-handed volunteers using functional magnetic resonance imaging (fMRI) of the entire brain. The finger to thumb opposition tasks each consisted of three conditions, two unimanual and one bimanual. Each experimental condition consisted of overt movement of the fingers in a prescribed sequence and imagery of the same task. An intricate network consisting of sensorimotor cortex, supplementary motor area (SMA), superior parietal lobule and cerebellum was identified when the tasks involved both planning and execution. During imagery alone, however, cerebellar activity was largely absent. This apparent decoupling of sensorimotor cortical and cerebellar areas during imagined movement sequences, suggests that cortico-cerebellar loops are engaged only when action sequences are both intended and realized. In line with recent models of motor control, the cerebellum may monitor cortical output and feed back corrective information to the motor cortex primarily during actual, not imagined, movements. Although parietal cortex activation occurred during both execution and imagery tasks, it was

most consistently present during bimanual action sequences. The engagement of the superior parietal lobule appears to be related to the increased attention and memory resources associated, in the present instance, with coordinating difficult bimanual sequences.

Naito E, Kochiyama T, et al. (2002). Internally simulated movement sensations during motor imagery activate cortical motor areas and the cerebellum. J Neurosci **22**(9): 3683-91.

It has been proposed that motor imagery contains an element of sensory experiences (kinesthetic sensations), which is a substitute for the sensory feedback that would normally arise from the overt action. No evidence has been provided about whether kinesthetic sensation is centrally simulated during motor imagery. We psychophysically tested whether motor imagery of palmar flexion or dorsiflexion of the right wrist would influence the sensation of illusory palmar flexion elicited by tendon vibration. We also tested whether motor imagery of wrist movement shared the same neural substrates involving the illusory sensation elicited by the peripheral stimuli. Regional cerebral blood flow was measured with H215O and positron emission tomography in 10 right-handed subjects. The right tendon of the wrist extensor was vibrated at 83 Hz ("illusion") or at 12.5 Hz with no illusion ("vibration"). Subjects imagined doing wrist movements of alternating palmar and dorsiflexion at the same speed with the experienced illusory movements ("imagery"). A "rest" condition with eyes closed was included. We identified common active fields between the contrasts of imagery versus rest and illusion versus vibration. Motor imagery of palmar flexion psychophysically enhanced the experienced illusory angles of plamar flexion, whereas dorsiflexion imagery reduced it in the absence of overt movement. Motor imagery and the illusory sensation commonly activated the contralateral cingulate motor areas, supplementary motor area, dorsal premotor cortex, and ipsilateral cerebellum. We conclude that kinesthetic sensation associated with imagined movement is internally simulated during motor imagery by recruiting multiple motor areas.

Nordin SM, Cumming J (2006). Measuring the content of dancers' images: development of the Dance Imagery Questionnaire (DIQ). J Dance Med Sci **10**(3-4): 85-98.

Mental imagery is the creation or re-creation of experiences in the mind and it is a common, yet under-researched area in dance. Indeed, although sport and exercise researchers have imagery measurement tools designed for their respective settings, no such tool has existed for dance. Having a valid and reliable questionnaire can produce information to form the basis for successful interventions to enhance both performance and well-being. Thus, the aim of this series of three studies was to create a questionnaire capable of assessing the frequency with which dancers image, entitled the Dance Imagery Questionnaire (DIQ). Studies 1 and 2 are primarily concerned with measurement development, while Study 3 also presents data that may be of more applied interest. A total of 1,068 female and male dancers from 25 dance forms and six experience levels (beginner to professional) participated in three cross-sectional questionnaire-based studies. There were 501 dancers in Study 1 (aged 23.26 [+ or -] 10.25 years), 317 dancers in Study 2 (aged 21.96 [+ or -] 6.63 years), and 250 dancers in Study 3 (aged 23.82 [+ or -] 9.16 years). Study 1 employed principal components analyses to determine that the DIQ consisted of 3 components: technique, mastery and goals, and role and movement quality. It was apparent that the mastery and goals component could also potentially split into two, producing a four-component solution. In Study 2, DIQ data were subjected to confirmatory factor analyses, from which a hierarchical solution emerged, with one higher-order factor and four second-order factors. The third study re-confirmed the hierarchical structure of the DIQ with a separate sample, and established the test-retest reliability of the questionnaire. Concurrent validity information is also provided concerning the relationships between dance imagery, imagery ability, self-confidence, and anxiety.

Nyberg L, Eriksson J, et al. (2006). Learning by doing versus learning by thinking: An fMRI study of motor and mental training. Neuropsychologia **44**(5): 711-7.

Previous studies have documented that motor training improves performance on motor skill tasks and related this to altered functional brain activity in cerebellum, striatum, and frontal motor cortical areas. Mental training can also improve the performance on motor tasks, but the neural basis of such facilitation is unclear. The purpose of the present study was to identify neural correlates of training-related changes on a finger-tapping task. Subjects were scanned twice, 1 week apart, with fMRI while they performed two finger-tapping sequences with the left hand. In-between scans, they practiced daily on one of the sequences. Half of the participants received motor training and the other half received mental training (motor imagery). Both training procedures led to significant increases in tapping performance. This was seen for both the trained and the untrained sequence (non-specific effect), although the gain was larger for the trained sequence (sequence-specific effect). The non-specific training effect corresponded to a reduction in the number of activated areas from an extensive set of brain regions prior to training to mainly motor cortex and cerebellum after training. The sequence-specific training effect involved the supplementary motor area and the cerebellum for motor training and visual association cortex for mental training. We conclude that gains following motor and mental training are based on distinct neuroplastic changes in the brain.

Olsson CJ, Jonsson B, et al. (2008). Motor representations and practice affect brain systems underlying imagery: an FMRI study of internal imagery in novices and active high jumpers. Open Neuroimag J **2**: 5-13.

This study used functional magnetic resonance imaging (fMRI) to investigate differences in brain activity between one group of active high jumpers and one group of high jumping novices (controls) when performing motor imagery of a high jump. It was also investigated how internal imagery training affects neural activity. The results showed that active high jumpers primarily activated motor areas, e.g. pre-motor cortex and cerebellum. Novices activated visual areas, e.g. superior occipital cortex. Imagery training resulted in a reduction of activity in parietal cortex. These results indicate that in order to use an internal perspective during motor imagery of a complex skill, one must have well established motor representations of the skill which then translates into a motor/internal pattern of brain activity. If not, an external perspective will be used and the corresponding brain activation will be a visual/external pattern. Moreover, the findings imply that imagery training reduces the activity in parietal cortex suggesting that imagery is performed more automatic and results in a more efficient motor representation more easily accessed during motor performance.

Roberts R, Callow N, et al. (2008). Movement imagery ability: development and assessment of a revised version of the vividness of movement imagery questionnaire. J Sport Exerc Psychol **30**(2): 200-21.

The purpose of this research was to amend the Vividness of Movement Imagery Questionnaire (VMIQ; Isaac, Marks, & Russell, 1986) in line with contemporary imagery modality and perspective conceptualizations, and to test the validity of the amended questionnaire (i.e., the VMIQ-2). Study 1 had 351 athletes complete the 3-factor (internal visual imagery, external visual imagery, and kinesthetic imagery) 24-item VMIQ-2. Following single-factor confirmatory factor analyses and item deletion, a 12-item version was subject to correlated traits / correlated uniqueness (CTCU) analysis. An acceptable fit was revealed.

Study 2 used a different sample of 355 athletes. The CTCU analysis confirmed the factorial validity of the 12-item VMIQ-2. In Study 3, the concurrent and construct validity of the VMIQ-2 was supported. Taken together, the results of the 3 studies provide preliminary support for the revised VMIQ-2 as a psychometrically valid questionnaire.

Rodriguez M, Llanos C, et al. (2008). How similar are motor imagery and movement? Behav Neurosci **122**(4): 910-6.

It has been suggested that motor imagery (MI) has the basic components of real motion. This possibility was tested here in 17 healthy volunteers studied while performing or imaging a fast sequence of finger movements of progressive complexity, a fast and precise extension of the arm to touch a small circle with the tip of a pencil, a periodic repetitive flexion-extension of the index finger at a specified rate, and a velocity-regulated continuous rotary movement of the right hand. Motor sequences of 4 to 5 fingers showed a real-virtual congruency similar to that previously reported with other equivalent tests, but it decreased in the simplest sequences performed with 1 to 2 fingers. A more marked decrease of real-virtual congruency was found in the experimental paradigm aimed at producing movements with a pre-specified velocity, which was low for rhythmic movements of the index finger and practically absent in the continuous rotary movements of the hand. Present data show that the ability of MI to produce "realistic" simulations of motion is not the same for all motor tasks.

Roth M, Decety J, et al. (1996). Possible involvement of primary motor cortex in mentally simulated movement: a functional magnetic resonance imaging study. Neuroreport **7**(7): 1280-4.

The role of the primary motor cortex (M1) during mental simulation of movement is open to debate. In the present study, functional magnetic resonance imaging (fMRI) signals were measured in normal right-handed subjects during actual and mental execution of a finger-to-thumb opposition task with either the right or the left hand. There were no significant differences between the two hands with either execution or simulation. A significant involvement of contralateral M1 (30% of the activity found during execution) was detected in four of six subjects. Premotor cortex (PM) and the rostral part of the posterior SMA were activated bilaterally during motor imagery. These findings support the hypothesis that motor imagery involves virtually all stages of motor control.

Sacco K, Cauda F, et al. (2006). Motor imagery of walking following training in locomotor attention. The effect of "the tango lesson". Neuroimage **32**(3): 1441-9.

The hypothesis of this study is that focusing attention on walking motor schemes could modify sensorimotor activation of the brain. Indeed, gait is a learned automated process, mostly regulated by subcortical and spinal structures. We examined the functional changes in the activity of the cerebral areas involved in locomotor imagery tasks, before and after one week of training consisting of physical and mental practice. The aim of the training was to focus the subject's conscious attention on the movements involved in walking. In our training, subjects were asked to perform basic tango steps, which require specific ways of walking; each tango lesson ended with motor imagery training of the performed steps. The results show that training determines an expansion of active bilateral motor areas during locomotor imagery. This finding, together with a reduction of visuospatial activation in the posterior right brain, suggests a decreased role of visual imagery processes in the post-training period in favor of motor-kinesthetic ones.

Short SE, Tenute A, et al. (2005). Imagery use in sport: mediational effects for efficacy. J Sports Sci **23**(9): 951-60.

The factors that influence whether an athlete chooses to engage in imagery are largely unknown. One reason may be the amount of confidence athletes have in their ability to image. The aim of this study was to examine the relationships among efficacy in using imagery, imagery use and imagery ability. Consistent with Bandura's (1986, 1997) theory, it was hypothesized that there would be a positive correlation between efficacy in using imagery and imagery use, and that efficacy in using imagery would mediate the relationship between imagery ability and imagery use. Participants were 74 female athletes from various sports. The instruments we used were the Movement Imagery Questionnaire-Revised (Hall & Martin, 1997) for imagery ability, the Sport Imagery Questionnaire (Hall, Mack, Paivio, & Hausenblas, 1998) for imagery use, and a modified version of the latter questionnaire for efficacy in using imagery. Correlations showed that the more athletes were confident in their ability to use a certain image, the more they used it. Efficacy in using imagery was found to mediate only the relationship between imagery ability and cognitive imagery use.

Stenekes MW, Geertzen JH, et al. (2009). Effects of motor imagery on hand function during immobilization after flexor tendon repair. Arch Phys Med Rehabil **90**(4): 553-9.

OBJECTIVE: To determine whether motor imagery during the immobilization period after flexor tendon injury results in a faster recovery of central mechanisms of hand function. DESIGN: Randomized controlled trial. SETTING: Tertiary referral hospital. PARTICIPANTS: Patients (N=28) after surgical flexor tendon repair were assigned to either an intervention group or a control group. INTERVENTION: Kinesthetic motor imagery of finger flexion movements during the postoperative dynamic splinting period. MAIN OUTCOME MEASURES: The central aspects of hand function were measured with a preparation time test of finger flexion in which subjects pressed buttons as fast as possible following a visual stimulus. Additionally, the following hand function modalities were recorded: Michigan Hand Questionnaire, visual analog scale for hand function, kinematic analysis of drawing, active total motion, and strength. RESULTS: After the immobilization period, the motor imagery group demonstrated significantly less increase of preparation time than the control group (P=.024). There was no significant influence of motor imagery on the other tested hand function (P>.05). All tests except kinematic analysis (P=.570) showed a significant improvement across time after the splinting period (P</=.001). CONCLUSIONS: Motor imagery significantly improves central aspects of hand function, namely movement preparation time, while other modalities of hand function appear to be unaffected.

Vergeer I, Roberts J (2006). Movement and stretching imagery during flexibility training. J Sports Sci **24**(2): 197-208.

The aim of this study was to examine the effect of movement and stretching imagery on increases in flexibility. Thirty volunteers took part in a 4 week flexibility training programme. They were randomly assigned to one of three groups: (1) movement imagery, where participants imagined moving the limb they were stretching; (2) stretching imagery, where participants imagined the physiological processes involved in stretching the muscle; and (3) control, where participants did not engage in mental imagery. Active and passive range of motion around the hip was assessed before and after the programme. Participants provided specific ratings of vividness and comfort throughout the programme. Results showed significant increases in flexibility over time, but no differences between the three groups. A significant relationship was found, however, between improved flexibility and vividness ratings in the movement imagery group. Furthermore, both imagery groups scored significantly higher than the control group on levels of comfort, with the movement imagery group also scoring significantly higher than the stretching imagery group. We conclude that the imagery had stronger psychological than physiological effects, but that there is potential

for enhancing physiological effects by maximizing imagery vividness, particularly for movement imagery.

Wriessnegger SC, Kurzmann J, et al. (2008). Spatio-temporal differences in brain oxygenation between movement execution and imagery: a multichannel near-infrared spectroscopy study. Int J Psychophysiol **67**(1): 54-63.

Near-infrared spectroscopy (NIRS) was used to assess human motor-cortex oxygenation changes in response to self-paced movements as well as movement imagery. We used a 24 channel NIRS-system which allows non-invasive monitoring of cerebral oxygenation changes in the human brain induced by cortical activity. From previous studies it is known that motor imagery activates sensorimotor areas similar to those activated during execution of the same movement. Sixteen healthy subjects were recruited and the changes in concentration of oxygenated hemoglobin (oxy-Hb) and deoxygenated hemoglobin (deoxy-Hb) were examined during a simple right and left hand tapping task and during kinesthetic movement imagery. All subjects showed significant increases in oxy-Hb during both tasks compared to the resting period, but with different onset latencies of oxygenation. During left and right movement imagery, the oxy-Hb concentration increased about 2 s later compared to real movement execution. Furthermore, the oxygenation found was bilaterally represented for both tasks but with temporal differences. The present study reported new results concerning timing and topographical distribution of the hemodynamic response during motor imagery measured by near-infrared spectroscopy.

Yaguez L, Nagel D, et al. (1998). A mental route to motor learning: improving trajectorial kinematics through imagery training. Behav Brain Res **90**(1): 95-106.

There are contrasting reports upon the level of effectiveness of motor imagery in learning new motor skills, but there is general consensus that motor imagery can lead to improvements in performance, especially in combination with physical practice. In the present study we examined the effectiveness of motor imagery in the acquisition of movement invariants in two grapho-motor trajectorial learning tasks with differing visuospatial components: 'Ideogram drawing' and 'connecting circles'. Two subject groups were studied: An imagery group, which underwent 10 min of motor imagery training and a control group, which practised a control visuomotor task over the same period of time. The results showed that imagery training alone enabled the subjects to achieve a significant approach to movement isochrony as well as a significant shifting of peak velocity toward the target. After a practice phase, both groups improved their performance, but the imagery group was still significantly faster than the control group. Furthermore, a series of tests measuring visual imagery abilities was administered to the subjects. There were however no significant relationships between the motor performance and the visual imagery ability levels of the subjects. It is concluded that motor imagery can improve the acquisition of the spatio-temporal patterns of grapho-motor trajectories and that there are different processes involved in visual and motor imagery.