Motor Imagery for Stroke Rehabilitation

Current Research as a Guide to Clinical Practice

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The practice of mental imagery is an internal, self-regulatory process of wish fulfillment.[1] As an integral part of goal-directed behavior, mental imagery affords the ability to visualize a possible future, act according to an imagined plan, and evaluate performance.[2] Rather than a series of actual "pictures" in the brain, mental imagery is a multidimensional, heuristic experience that shares a number of features with other aspects of cognitive processes integral to motor control, such as attention, perception, planning, visuospatial reasoning, and memory.[3]

The expression of an image is one way implicit cognitive information is made explicit.[4] Seeing with the "mind's eye" through spontaneous- and guided-imagery has been integral to individual and communal healing rituals for thousands of years.[5] The transformational power of imagery to heal disease through memory, dreams, and hallucinations has been reported in many testimonials even in modern Western medicine.[6]

An expression of mind–body integration, imagery can be expressed through various modalities (visual, auditory, gustatory, proprioceptive, or synesthetic).[7] It is the mental practice of *motor* imagery [author's italics], however, that is particularly relevant to physical medicine and rehabilitation.[8] Motor imagery practice (MIP) involves imaging whole, complex tasks or succinct components of tasks while inhibiting actual movement. MIP is distinguished from other forms of imaging in that clinical protocols are designed to simulate functional tasks.

Mentally practicing motor imagery has been shown to be effective in for enhancing motor learning and performance, helping healthy, (i.e., non-neurologically impaired) persons acquire new skills, modify older skills, alter maladaptive habits, and overcome psychologic or physical obstacles.[9] This article is a review of the feasibility of applying MIP to improve functional recovery in persons after stroke. This review includes the basic theories and outcome measures of MIP in recovery of upper-extremity function after stroke.

Background

During the twentieth century, research in mental imagery as a tool for motor learning emerged from relative obscurity to become a highly researched area in sports psychology and cognitive neuroscience.[10] An operational definition of MIP is the intentional learning or improving of a motor skill through covert, imagined practice of that skill without simultaneous sensory input while overt muscular contractions or movements are inhibited.[11]

A rich body of literature, spanning at least 4 decades, exists that largely supports MIP in competitive sports and exercise.[12,13] While nearly100 percent of sports psychologists and coaches currently use some type mental imagery for training athletes to cope with the stress of competition and to gain a competitive edge, no one technique, training, or protocol has been universally accepted for sports in general or for any one sport in particular.[14]

Practicing motor imagery is a noninvasive, painless, and safe, self-guided or self-paced technique that is physically nonfatiguing, simple to administer, and cost effective.[2] MIP stimulates a variety of cognitive perceptual processes integral to motor control, (motivation and memory, for example), as well as activating autonomic functions to the same degree as physically executed actions.[7,15] In rehabilitation, MIP affords clinicians a high degree of creativity and flexibility for designing customized, meaningful, and effective images for patients to achieve functional goals.[16] MIP's use in treating motor dysfunctions, however, has not achieved widespread use in any orthopedic or neurologic setting.[8]

The formal use of mental imagery still is considered alternative or adjunctive to conventional medicine and is restricted largely to patients with terminal illnesses.[6] Support has come from brain-mapping researchers in the last decade documenting plastic changes in the brain through comparing imagined and physically executed actions.[17] While these studies have helped integrate the use of mental imagery practice into conventional medicine, development of protocols has been hindered, however, by inconsistencies in research methods and lack of clear-cut, evidence-based results.[18,19] This, coupled with small heterogeneous samples of subjects, has hindered the development of protocols with adequate construct validity to guide practice, especially for patients who have had strokes.[20,21] Finally, there are challenges inherent in technological and clinical accuracy in measuring mental imagery's ephemeral and subjective attributes.

MIP is not one undifferentiated ability but a multidimensional process.[3] At least 5 major motor learning functions for sports psychology have been identified: (1) cognitive-specific (mental practice of one specific aspect of a sport or skill [e.g., free throw]); cognitive general (mental practice of a whole skill [e.g., an entire gymnastic routine]); (3) motivational-specific (e.g., setting a specific goal and [re]evaluating performance); (4) motivational general-mastery (e.g., practicing imagery related to self-regulation, self-confidence, and self-efficacy); and (5) motivational general-arousal (e.g., using "psyching up" strategies to either increase or decrease competitive anxiety).[2]

In MIP, the imager has enough cognition to know he or she is awake and not dreaming, and enough memory to know that the image mirrors a real, physical movement experienced in the past.[11] Motor imagery can be experienced from two perspectives: (1) external, as if the imager is seeing the image like a movie—outside of him- or herself—;and (2) internal, as if the imager is experiencing all the sensations connected with executing the image. In the former ("visual" imagery or "third person" imagery), the movement performance is projected outside of the self. In the latter ("kinesthetic" imagery or "first person" imagery), a more internal or embodied state of movement is experienced, in which the imager feels the tension or pressure, the speed of movement, et cetera, within the image.[11,15]

Many synonyms exist for this complex cognitive behavior. The terms "mental practice," "mental rehearsal," and "visuomotor behavior rehearsal," "covert rehearsal," "covert modeling," "ideokinesis," and "ideokinetic facilitation," are some of the more common terms that have been used somewhat interchangeably.[2,16,22] Researchers and therapists should choose carefully among the techniques when designing research to avoid confounding or contaminating influences. Mental imagery might be prescribed alone, for example, or in combination with relaxation training and/or verbal motivational cueing or hypnotic suggestion.[8,22] Relaxation training, often included as an accompaniment to mental practice[11] and "visuomotor behavior rehearsal[23] protocols, may not be critical to the success of mental imagery, but may influence other variables.[24]

Theoretical Foundations

No one theory is comprehensive enough to explain how mental imagery works.[2] Composite theories are evolving.[8] Sports psychologists have subscribed predominantly to two theories, the psychoneuromuscular theory (PNM) and the symbolic learning theory (SLT), both of which briefly described below. Two additional theories exist that help explain the motivational (the arousal theory, and brain computational (the bioinformational theory) aspects connected with cognitive processing.[23]

The oldest—and most widely supported—theory is the PNM theory, which links mental processes with specific physiologic processes through electromyography (EMG) recordings.[24,25] Imagined movements produce low level EMG impulses (identical minute innervations) localized to the muscles similar to those actually involved in physical execution of an action. Mental imagery of a motor action may activate internal feedback mechanisms that can lead to muscle stimulation, resulting in the same effect on motor performance as actual physical movement.[26]

Critics of the PNM theory have raised four issues based on research evidence:

(1) They claim that EMG activity following mentally practicing motor imagery lacks specificity in that, not only the muscles specific to the task, but also general, nonspecific muscles are stimulated.[15]

2) EMG recordings in some studies have confirmed that the same skeletal muscles activated by imagery are identical to those activated by motivational and arousing cues.[27]

(3) Strength gains following imagery training appear to come, not from peripheral neural changes or muscle hypertrophy, but from changes at higher levels of motor planning and control.[28]

(4) Priming of the specific muscles of an action does not necessarily lead to motor learning for that task.[29] In summary, the PNM theory alone is considered to be too simple and imprecise to account adequately for motor learning in complex environmental conditions.

From the 1930s to the 1960s, behaviorists spawned a different theoretical construct, emphasizing cognitive over the physiologic processes.[30] In 1934, Sackett evolved the SLT[31] in which motor actions were conceived as abstract mental blueprints that had circuits that could be strengthened through repetition (imagined or actual), elaboration, and memory.

Proponents of SLT argued that the effects of mental imagery were not caused by little pictures in the brain (images) per se, but by more abstract coding of elements of motor processing.[32] Mental imagery afforded the opportunity to rehearse the sequence of "symbolic components" of a movement task, that is, the nature of the action, anticipated consequences, and strategies for choosing a different course of action.[7]

Opponents of SLT claim that the validity this theory hinges on the degree to which a task is cognitive.[12] The more cognitive the task is, the easier it is to apply and benefit from mental imagery, especially in the early stages of skill learning, in which a high degree of cognition is required.[32] Tasks or sports that require more problem solving (e.g., golf) or strategic moves (e.g., team sports) are considered to have a higher cognitive content that is facilitated by mental imagery.[25] Meta-analyses of mental imagery in sport performance have shown an increased effect size when the task is more cognitive (e.g., finger-maze learning)[33] than purely motor (e.g., weight lifting).[25] Improved controls on studies are needed when comparing task characteristics.[12]

Neurophysiologic Correlates

Neuroimaging studies—of healthy subjects and those with stroke—have shown that the neurologic structures activated during imagined actions are the same as those activated during physical execution of the same actions.[26,34] Physical movements and imagined movements, similarly, activate large portions of the brain, both cortical and subcortical, including the premotor cortex, supplementary motor cortex, primary sensorimotor cortex, visual cortex, cingulated gyri, inferior parietal lobules, basal ganglia, and cerebellum.[35]

Imagery-related effects have been attributed to experience-dependent changes in higher-level regions of the brain: those involved more in motor planning than in the execution of movement.[15] As to whether the primary motor cortex is activated during imagined action,[36] this has been clearly demonstrated with improved technological accuracy.[37] The primary motor cortex, in fact, is activated during imagined action, although to a lesser degree than occurs with actual physical movement.[38]

Repeated, forced use of an affected limb after stroke has been shown to induce plastic reorganization of the brain.[39] Research in motor imagery in both healthy subjects and those with stroke, has lead to the hypothesis that mental practice also induces plastic changes, particularly in the sensorimotor cortex.[21] Whether preparing to actually move, or imagining it, the same areas are activated,[40] even to a large extent within the same timeframe.[15]

Johnson showed, in 11 subjects with subacute stroke, that imagined movements were represented as accurately as those of healthy controls. Subjects participated in a computerized reach-and-grasp task in which they imagined grasping a dowel positioned in 8 different spatial configurations. Results showed that all subjects retained the ability to imagine a biomechanically feasible grasp (either overhand or underhand) for both limbs.[41] This capacity to imagine physical actions accurately after stroke has even been demonstrated in a case study of a person with locked-in syndrome.[42]

Differences in imaging ability between those with and without brain damage (given that intact memory exists) lie more in the timeframe and in the complexity of the task.[43,44] Movement times—both imagined and executed —are slower in general for an impaired limb after stroke.[42,45] The more complex the task is, involving more body parts and more complex relationships to the body or space, the more slowly persons who have had strokes will be able imagine the actions required to complete the task (for either limb)—a phenomenon known as Fitt's Law.[46]

Researchers studied subjects with parietal-lobe damage and consequent apraxia, showing that, as movement (of either limb) becomes more complex in terms of number and positional relationships of body parts, time to execute the movement becomes slower. [44] These researchers hypothesized that an intact parietal lobe was necessary to generate an internal, kinesthetic image of the body correctly.[45]

The effectiveness of motor imagery for altering motor behavior hinges on many other variables, both intrinsic (physical and cognitive aspects) and extrinsic (practice conditions).[12] The type of stroke, for example, site and extent, degree of comorbidity, and psychologic and memory status influence the location, time, and degree of activation of various areas of the brain.[21] The type of task, the nature of the image (dynamic or static) and its vividness, and the mode of image (visual, auditory, gustatory, etc.) will also exert an influence.

Functional Gains in Stroke Rehabilitation

Within the last decade, a number of researchers have supported the use of MIP for functional recovery after stroke.[21] The bulk of the imaging studies have been on finger movements,[17] with lower-extremity studies restricted to non-neurologically impaired (healthy) subjects.[40,47] This may be because small, discrete finger movements help minimize distortion while acquiring imaging data during scanning. Clinical research using motor imagery practice in stroke recovery also has mainly addressed upper-extremity outcomes over lower-extremity outcomes,[17] perhaps because functional upper-extremity movements can be performed or imagined more readily or in sitting, as opposed to standing and walking, when environmental forces are compounded and more extensive, higher brain centers are recruited to meet complex environmental demands.[20,47]

An exception to studies on limbs includes Niemeyer's research on 7 subjects with visual inattention and neglect, whose scores improved on a psychometric battery of tests after using an imaginary visual scanning technique (imagining the sweep of a lighthouse beam).[48]

In a 1988 review, Warner and McNeill[16] supported the efficacy of MIP as an adjunct to physical rehabilitation, but only a few, modest attempts followed, incorporating mental practice of motor imagery into orthopedic rehabilitation.[49–51] By the mid-1990s, researchers initiated mental practice of motor imagery as an adjunct to restoring function after stroke.

In several separate studies, Page and colleagues reported improved scores in subjects with subacute stroke on two validated tests of functional recovery, the upper-extremity portion of the Fugl-Meyer Motor Assessment and the Action Research Arm tests.[52,53] While the motor-imagery protocol was conducted concurrently with occupational therapy, Page and colleagues attempted to control for dosage and impairment levels.[53]

Yoo and colleagues observed significant both qualitative (mean line error) and quantitative (EMG recordings of the trapezius) improvements after mental practice sessions, in 3 patients with subacute hemiparesis (moderately to severely impaired) in drawing horizontal and curved lines.[54] The results indicated that subjects who were minimally impaired showed least improvement, possibly because they were already adept at the particular skill tested and possibly might have lost motivation and gotten bored by repetitive tasks. However, initial data in Page's studies suggested that patients who are severely impaired may also not benefit as much from motor imagery practice because "appropriate skill-specific motor schema must be in place" on which practice can build.[21]

Reporting precise protocols and amounts of MIP has been lacking. Research studies frequently appear to be contaminated by addition of relaxation training to the imagery protocol, or the articles of protocols are not written in enough detail to determine the degree of control, an exception being one review of MIP in stroke rehabilitation, offering amount guidelines and techniques for controlling extraneous variables.[20]

Weiss and colleagues reported their protocol for motor imagery practice clearly when examining the effects of EEG and EMG recordings in 12 subjects with left-sided hemiparetic stroke. This was not a functional outcomes study. Changes were observed in both affected and unaffected sides in the subjects. There were significant decreases in mean spectral power density in the theta (central and parietal regions), alpha (central region), and beta-1 frequency bands, commensurate with those of healthy subjects.[55]

Additional challenges to the validity and reliability of the research initiatives in the last decade have been small samples and effect sizes, lack of control of certain key patient characteristics (type of strokes and locations and extents of lesions) and deficits (such as visuospatial neglect and cognitive deficits). Confounding variables have also included lack of establishing operational definitions for imagery, lack of validated psychometric instruments for measuring imaging ability in persons with stroke, concurrent physical therapy and other treatment modalities with the imagery protocols, and other methodological problems that made it difficult to determine the true impact of MIP. While initial studies show promise, tighter controls and accountability for methods are necessary to allow for generalizability.

Outcomes

Outcomes of training vary with the individual perspective, the desired outcome, and the environmental conditions.[2] In addition, attempts to measure mental imagery as a single trait, create problems with sensitivity, reliability, and validity.[33]

A sports psychologist (Murphy), reviewed approximately 200 published imagery studies reviewed, with no two appearing to measure the same thing in terms of training or delivery. In isolation, many studies appeared to be sound, but together, they formed an unregulated, unreliable, and invalid body of research. Murphy further the process of measuring mental imagery criticized, stating that mental imagery cannot be prescribed or measured in the same fashion as a medical "dose," especially when the basic question of how mental imagery mimics the effects of physical action has not been answered.[33]

Intrinsic variables alone are extensive and difficult to measure. These include attention, motivation, previous level of physical skill, imagination, creativity, absorption, and the ability to self-pace without mental fatigue; all play important roles in outcome effectiveness.[11,12]

A variety of psychometric instruments were developed between 1909 and 1986, to measure image content (mode and task), intensity (vague to vivid), controllability (mental manipulation or rotation of an image), and personal perspective.[13,19] All are pencil-and-paper, self-reporting instruments that are easy to administer to non-neurologically impaired individuals. The tests are used to measure self-awareness (can the person distinguish between consciousness and dreaming?), vividness (how clear is the image?), and controllability (can the person manipulate or rotate of the image mentally?).[12]

The Questionnaire on Mental Imagery,[56] a 150-item questionnaire shortened to 35 items by Sheehan[57]; the Gordon Test of Visual Imagery Control,[58] shortened by Richardson[11]; the Individual Differences Questionnaire[59]; the Movement Imagery Questionnaire [60,61]; and the Vividness of Movement Questionnaire [62] predominantly use Likert-style scales. The scales have ordinal ratings of 1–5, or more in descending order (1, "perfectly clear as normal vision"; 2, "clear and reasonable"; 3, "moderate"; 4, "vague/dim" ; and 5,"only know you are there in the room, but no image is generated.")[62] While most of the assessments have acceptable interrater reliability, construct-validity[18] and concurrent validity remain questionable.[1]

Since the late 1980s, few valid psychometric tools or intervention techniques specific to mental practice of motor imagery have been developed[18] or redesigned and reevaluated for reliability and validity.[64] A Kinesthetic Imagery Questionnaire (adapted from the Movement Imagery Questionnaire) has been evaluated and has excellent test–retest reliability and adequate internal consistency suitable for elderly subjects and patients with certain types of brain damage.[65]

Practice Conditions

Many extrinsic variables can make an impact on practice conditions, including the amount, time, length, and number of trials within and between practice sessions, and the nature of the tasks and their familiarity. Practice protocols vary widely among athletes, with details largely being anecdotal.

While physical practice is essential for learning or refining any motor skill, particularly in stroke rehabilitation,[21] having a mental image of the action to be accomplished is not always present or needed in motor performance.[7] However, motor imagery can, when combined with physical practice, enhance its effects. Evidence exists, however, suggesting that mental practice combined with physical practice actually accelerates motor learning and improves physical performance more than physical practice alone,[66] even with populations of patients who have neurologic impairments.[17]

Since 1982, sports researchers have adhered to the ideas that mental practice, plus physical practice results in a better motor outcome than physical practice alone and physical practice alone has a better motor outcome than mental practice alone. Some findings suggest, however, that mental practice is as effective as physical practice, at least for some sports (bowling, putting, drawing)[67,68] and even modest gains in physical performance can result from mental practice alone (darts).[69]

This finding might be of particular interest to clinicians in view of effective outcomes for patients with neurologic impairments. The findings have been established mainly in interventions requiring extensive, repetitive[39] practice that is intensively focused.[70] While practice protocols are debatable, mental imaging practice can substitute for physical practice when athletes are injured, fatigued, traveling, or otherwise unable to engage in physical practice.[71] MIP has helped increase the number of exercise repetitions among healthy elderly women without subjective reports of fatigue[72]and improved exercise compliance and feelings of self-efficacy in other subjects.[50]

Determining the right amount of MIP, or more precisely, the amount of mental practice combined with physical practice, is still debated, especially for persons with stroke. Different practice ratios have evolved for athletes[66] but not for persons with stroke.[17] In either case, it is difficult to determine whether a particular person is imagining a task vividly and correctly with each repetition. While support exists for training benefits for people with low imaging ability, more research is needed to substantiate these benefits for healthy individuals and those with various types of disabilities.[29]

Conclusions

These initial research studies describe how MIP shows promise in stroke rehabilitation. Intrinsic variables have not yet been controlled adequately, however, and tasks have not been adequately studied and controlled, neither for sports, nor for neurologically impaired individuals. More questions than answers remain regarding assessment and measurement to determine which patients can best benefit from motor imagery practice. Honing of imagery inventories, refining the reliability and validity of research designs, and establishing larger studies on different populations is needed for generalization of results. As clinicians shift from impairments-based practice and toward more wholistic approaches to practice, future researchers in physical therapy might find efficacy in using mental practice of motor imagery as a therapeutic tool in motor learning for patients with neurology impairments. □

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