REVIEW

Aberrant learning in individuals who perform repetitive skilled hand movements: Focal hand dystonia—Part 1

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Summary Stressful, repetitive use of the upper limb in work, sports, or musical performance can lead to acute, pain and loss of function. The evidence for tissue microtrauma as the underpinnings of this pain is convincing and explains why rest, anti-inflammatory medications, change in movement biomechanics and good ergonomics are usually effective treatment modalities. Unfortunately, some repetitive strain injuries become chronic with degenerative changes found in tendons and muscles, scarring restricting soft tissue and joint mobility and compression of peripheral nerves causing strain and limiting excursion. In other cases, involuntary co-contractions of flexors and extensors lead to painless, uncontrollable, end range twisting movements that interfere with the performance of target tasks. This movement dysfunction is referred to as occupational hand cramps, focal hand dystonia (FHD), golfers yip, keyboarders cramps, or musician’s cramps. Research studies report evidence of degradation of the somatosensory, sensorimotor and motor representation of the hand in animals and patients with dystonic hand movements. This aberrant learning requires learning based training to reorganize the brain. In this presentation, the principles of neuroplasticity will be related to the origin, diagnosis, assessment and treatment of FHD grounded on an evidence-based review of the research to support aberrant learning as one etiology for the origin of this disorder and the foundation for a learning based approach to remediate the condition.

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The problem

Focal dystonia is a devastating movement disorder that affects more than 1 million individuals in the US (Sheehy and Marsden, 1982; Lockwood, 1989; Hochberg et al., 1990; Marsden and Sheehy, 1990). In contrast to generalized dystonia, which may affect the entire body, focal dystonias present in the context of performing a specific motor task usually with only one part of the body affected. When patients attempt to perform that target task, they experience involuntary co-contractions of flexor and extensor muscles (Altenmueller, 1988). The ability to perform finely graded and sequenced movements is disrupted and replaced by crude, uncontrolled, twisting and writhing movements (Rosenbaum and Jankovic, 1988). In some patients, an enduring focal hand dystonia (FHd) is expressed only in the context of one specific posture and task; in others, it can slowly generalize to other related hand postures and uses, and can ultimately disable the entire hand (Utting, 1995). Although the disorder is typically painless, some patients may have painful spasms and others can experience increased sensitivity, a sense of dullness or even numbness of the affected limb.

Although there is some evidence that focal dystonia is a genetic disorder (Gasser et al., 1999), FHd can develop in individuals who perform excessive, repetitive movements in the workplace (Hochberg et al., 1990; Hochberg and Hochberg, 2000; Byl, 2004). For example, FHd is common among butchers, assembly line workers, computer keyboard and mouse users, and musicians. An increase in its frequency of occurrence has been associated with industrialization and specialization of work. FHd has been reported in about 0.5% of office workers and 7–8% of musicians (Tubiana and Chamagne, 1983; Newmark and Hochberg, 1987; Hochberg and Hochberg, 2000; Lim et al., 2001; Tubiana, 2003).

The evidence for microtrauma from repetitive overuse of the upper limb is convincing (Barr and Barbe, 2002; Barbe et al., 2003). Rest, anti-inflammatory medications, change in biomechanics and good ergonomics are usually effective treatment modalities. Unfortunately, some individuals must continue to work despite their symptoms. When this type of injury becomes chronic, degenerative changes are found in tendons and muscles (Barbe et al., 2003). Scarring restricts soft tissue and joint mobility (Barr and Barbe, 2002), and compression of peripheral nerves causes strain and limits excursion (Edgelow, 1992; Charness et al., 1996; Pitner, 1990; Stock, 1991). In some cases, chronic neuropathic pain develops (Clark et al., 2003), while in other cases, patients complain about fatigue and clumsiness of the hand often associated with a tremor (Fernandez-Alvarez et al., 2003). If these individuals do not take time away from work, a FHd (occupational hand cramp) can develop. In the last ten years, there is increasing research evidence of degradation of the somatosensory representation of the hand in animals and patients with dystonic hand movements. If one possible origin of FHd is aberrant learning and degradation of the cortical hand representation, then treatment must include learning based training strategies to reorganize the brain (Sanger and Merzenich, 2000).

Retraining the brain: the evidence for neuroplasticity

Our hands allow us to perform delicate, complex, individuated, fine motor movements (Gerloff et al., 1998; Sherrington, 1906; Hebb, 1949; Johanson, 1996). These fine motor movements require accurate sensory inputs and accurate sensory feedback. These skillful movements are associated with large, orderly, somatotopic, highly differentiated representations of the hand in the thalamus, basal ganglia, somatosensory cortex and motor cortex (Kaas et al., 1979; Merzenich, 1996; Merzenich and Jenkins, 1995; Penfield, 1950; Wang et al., 1995; Stryker et al., 1987). Integrative functional representations of well learned tasks (e.g. instrumental play or writing) are also mapped on the cortex (Rijntjes et al., 1999).

These topographical representations can be modified over a lifetime by injury, aging, chronic pain or attended repetitive behaviors (Jenkins et al., 1990a, b; Merzenich and Jenkins, 1993). These behaviors can lead to positive adaptation or negative adaptation. For example, situations such as deprivation, drugs, head trauma, degenerative diseases are known to degrade the topographical representation of the hand. However environmental and personal enrichment in addition to attended, rewarded, spaced, repetitive, learning based, goal-directed, nonstereotypical, progressive practice can lead to positive changes (Byl and Merzenich, 2001; Jenkins et al., 1990a, b; Wang et al., 1994, 1995; Hasselmo, 1996; Byl et al., 2000a, b; Xerri and Merzenich, 1998).

Task practice (mental or physical) enhances the efficiency of learning new tasks, improves task proficiency, and increases recovery following neural insults (Elbert et al., 1995; Elbert et al., 1998; Jenkins et al., 1990a, b; Karne, 1995; Merzenich
et al., 1996; Spengler et al., 1997; Nudo and Plautz, 2001; Nudo et al., 1996b; Nagarajan et al., 1998). These task-specific learning based repetitive behaviors drive selective changes in cortical cell differentiation and selective specialized representations.

The physiological changes occur near simultaneously with the emergence of more efficient, accurate and differentiated behaviors (Recanzone et al., 1990, 1992a–e). With learning based training, there is an up-regulation of neurotransmitters such as dopamine and acetylcholine (Gil et al., 1997; Juliano and Eslin, 1991). Changes in neural organization include expansion of cortical representations, narrowed columnar spread of the digits on the cortex, co-selection of complementary inputs, increased excitable neurons, enhanced salience and specificity of feedback, increased myelination, strengthened synapses between coincident inputs, shortened integration time, and increased complexity of dendritic branching (Allard et al., 1991; Penfield, 1950; Merzenich et al., 1983, 1984; Yang et al., 1992; Xerri et al., 1996, 1999; Spengler et al., 1997; Nudo, 2003). In addition there is a reduction in the size of receptive fields as well as increased density of receptive fields on the digits (Jenkins et al., 1990a, b). The topography of the cortex can also change depending on the type of injury. For example, the topographical map is not only modified following a central insult such as a stroke or a head injury, but the topography is also changed when a peripheral nerve is injured. The map can resume normal topography after regeneration of the nerve (Wall et al., 1983, 1992). Further, new synaptic networks are refreshed and poor connections can be erased as a result of variation in inputs, metabolic state, emotions, sleep, and natural endorphins (Jenkins and Merzenich, 1987; Elbert et al., 1997; Byl and Merzenich, 2001).

Unfortunately, neural plasticity is not infinite; there are inherent limits based on physiological time constants, inhibition, and integration time (Sanger and Merzenich, 2000). For example, rapid inputs occurring within the inhibitory or integration period, may no longer be registered as temporally distinct (Woolsey, 1958; Wang et al., 1995; Byl et al., 1996, 1997; Byl and Melnick, 1997; Chen and Hallett, 1998; Bara-Jimenez et al., 1998; Sterr et al., 1998; Pascual-Leone, 2001). In this case, stimulated skin surfaces form a unified rather than a unique spatial and temporal representation in the cerebral cortex (Byl et al., 1996a,b; Elbert et al., 1995, 1998). Specificity of digital representation is critical to the maintenance of the normal sensory organization, sensorimotor feedback and fine motor control of the digits (Gelkopf et al., 1993; Pascual-Leone et al., 1995).

Evidence-based review of central consequences of repetitive overuse of the hand: etiology of occupational hand cramps: aberrant learning

Occupational hand cramps (or FHd) is considered idiopathic. However, individuals performing tasks requiring intensive repetitive movements (e.g. working at computer, playing an instrument, pitching a ball, screwing nails, playing golf) appear to be at high risk. Performing artists often report having achieved a new high level of performance using new techniques or a new instrument to be suddenly followed by involuntary, writhing, twisting end range postures of the digit that make normal musical performance impossible (Altenmüller, 1988, 2003; Rothwell, 1983; Newmark and Hoberg, 1987; Cohen and Hallett, 1988; Jankovic and Shale, 1989; Hochberg et al., 1990; Marsden and Sheehy, 1990; Bell et al., 1994; Utti et al., 1995).

It is hypothesized that focal dystonia, specifically cervical dystonia may be genetic (Illarioshkina et al., 1988; Gasser et al., 1996; Leube et al., 1996; Ozelius et al., 1997). In both general and focal dystonia, there is also strong evidence of an imbalance of inhibitory and excitatory pathways in the globus pallidus/substantia nigra (DeLong et al., 1985; DeLong, 1990; Perlmutter et al., 1997; Black et al., 1998).

Other researchers report hand dystonia could result from cortical motor dysfunction (Chase, 1988; Defendini, 1988; Gilman et al., 1988; Tempel and Perlmutter, 1993; Deuschl and GodeMeier, 1998; Toro et al., 2000), degradation in the sensory thalamus (Utti et al., 1995; Zirh et al., 1998; Lenz and Byl, 1999), or disruption in cortical sensory activation, somatosensory representation or spatial perception (Byl et al., 1996, 1997; Chen and Hallett, 1998; Elbert et al., 1998; Tinazzi et al., 1999; Bara-Jimenez et al., 2000a,b; Butterworth et al., 2003; McKenzie et al., 2003; Tinazzi et al., 2003).

Different researchers report abnormal gating of somatosensory inputs, (Murase et al., 2000) abnormal presynaptic desynchronization of movement, abnormal muscle spindle afferent firing (Grunewald et al., 1997; Toro et al., 2000), or disruption of inhibition in the spinal cord (Chen et al., 1995; Kaji et al., 1995; Nakashima et al., 1989; Naumann and Reiners, 1997; Panizza et al., 1989, 1990). Some physician scientists have evidence suggesting FHd develops as a consequence of peripheral trauma, peripheral nerve entrapment or anatomic restrictions in soft tissue (Charness, 1993; Charness et al., 1996; Jancovic, 2001; Charness et al., 1992, 1993;
Leijnse, 1997; Quartarone et al., 1998; Topp and Byl, 1999; Weiner, 2001; Wilson et al., 1993). The most controversial hypothesis is that FHD results from aberrant learning (Blake et al., 2002a, b; Byl et al., 1996, 1997, 2003).

In 1996, Byl et al. proposed the sensorimotor learning hypothesis as one etiology of work related FHD. Repetitive use simultaneous firing, coupling of multiple sensory signals, and voluntary co-activation of muscle, leads to a degradation of the sensory cortical representation of the hand and disruption in sensorimotor feedback (Merzenich et al., 1984, 1990, 1996, 1999; Byl et al., 1996, 1997; Nudo and Milliken, 1996; Nudo et al., 1996a; Merzenich and Kaas, 1983, p. 322; Merzenich, 1999; Wang et al., 1995; Xerri et al., 1999). However, in 1997 (Byl et al., 1997) also reported that not all primates trained with sufficient intensity to develop these motor control problems.

Sanger and Merzenich (2000) elaborated on this hypothesis, proposing an integrated multi-system Computational Model to explain the origin of FHD. If the sensorimotor loop gain and the neural circuitry connecting the deep cortical nuclei, basal ganglia and thalamus are unstable, then a focal or a general dystonia could develop, depending on the extent of the imbalance across multiple sensory and motor systems (Groenwegen et al., 1990; Sanger and Merzenich, 2000). The computational model could explain why symptoms of dystonia:

(1) develop in otherwise healthy individuals who perform highly attended repetitive movements;
(2) evolve variably in time;
(3) appear only during the performance of a target specific task;
(4) persist even when the task is no longer performed;
(5) decrease, but are not be remediated with dopamine-depleting drugs or botulinum toxin; and
(6) are associated with abnormalities in somatosensory, sensorimotor and motor representations of the dystonic limb.

Based on the sensorimotor learning hypothesis integrated within the computational model, appropriate treatment must decrease the imbalance in the loop gain by re-differentiating cortical and subcortical representations. If the dystonia is severe, it is necessary to temporarily break the cycle (e.g. botulinum toxin injections) before retraining can be effectively implemented. This retraining must be based on the principles of neuroplasticity. Pathological connections must be uncoupled and selective movements must be practiced to engage specific and relevant sensory neurons and increase uncorrelated movement component.

Clinical assessment and diagnosis: repetitive strain injury-focal hand dystonia

Sometimes it may be years before the diagnosis of FHD is made. The physical examination is considered normal despite the complaints of the patient about loss of control of movement at the target task. There is no laboratory test for FHD. The diagnosis of FHD is made by a careful history and observation during performance of the target task. It is possible the onset of the hand dystonia could have been a consequence of trauma (Jancovic, 2001; Weiner, 2001). Thus past trauma or recent trauma must both be considered risk factors particularly if: (1) the trauma history revealed a strong temporal-anatomical relationship to the onset of FHD: (2) the trauma was severe enough to cause persistent local symptoms and lead to late medical attention: (3) the anatomical site of the original injury was the same site as the initial manifestation of the movement disorder; (4) the movement disorder developed within days or months, (up to a year) post injury and; (5) there were preexisting contractures and limitations of passive movement in the area of the involved limb (Jancovic, 2001).

FHD has also been reported in patients with a history of high stress, recent change in levels of stress, periods of intensive repetitive hand use, job instability, application of new techniques, change in equipment, increased time on task to improve quality of performance, quantity of work produced or intensity of time committed to improve performance (Kolle, 2000). Most frequently, the initial complaint preceding the development of hand dystonia is pain from inflammation and swelling as a consequence of tissue microtrauma (Salmon et al., 1995; Viikari-Juntura and Silverstein, 1999; Barr and Barbe, 2002; Barbe et al., 2003; Clark et al., 2003). These individuals continue to perform the repetitive work. Some go on to develop chronic pain or degenerative tendinosis (Kahn et al., 1999), while others begin to complain of task-specific fatigue, incoordination or involuntary movements instead (Cohen and Hallett, 1988). Personality characteristics such as perfectionism, anxiety, stress, phobias, and emotional instability may also be abstracted from the history from those who develop a FHD (Jabusch et al., 2001; Altenmuller et al., 2002).
Table 1  Principles of neuroplasticity (neural adaptability).

(A) The scale of plasticity in progressive skill learning is massive. Although the greatest plasticity occurs during development, the potential for neural adaptation continues throughout life. Research also suggests that plasticity may even be excessive in some individuals (e.g. allowing an individual to drive change from a positive to a negative state). We know that learning is modulated as a function of behavioral state and while the nervous system can adapt with a powerful single behavioral event, enduring behavioral changes result from attended, repetitive, learning behaviors which modify local neuroanatomy and neurophysiology. This type of learning requires a commitment of the patient, insight of the therapist, support of the family and technology. Learning activities must be compelling and may include robotic devices, mental imagery and practice, computer gaming and virtual reality experiences. To maximize learning:

1. Activities must be attended-goal directed
2. Behaviors must be motivating/fun
3. Behaviors must be repeated (and variable)
4. Behaviors should be linked temporally and spatially but not simultaneous in time
5. Behaviors must be rewarded
6. Give feedback on performance accuracy
7. Make stimulus strength adequate for detection
8. Stimulation and behavioral expectations must be progressed in difficulty
9. Stimulus-induced behaviors need to be integrated into meaningful function
10. Behaviors should be age appropriate
11. Behaviors should be integrated across sensory modalities
12. Make sensory input relevant to desired outputs
13. Repeat behaviors over time
14. Match training behaviors with recovery/developmental periods
15. Strengthen responses with multisensory modalities
16. Begin stimulation by using the most mature or capable sensory receptors
17. Behaviors should be performed in different environmental contexts
18. Do training in the gravitational positions that facilitate task achievement
19. Preferred behaviors must be rewarded and negative behaviors discouraged
20. Accurate, normal behaviors must be repeated

(B) Neurophysiological and neuroanatomical changes can be measured in the central nervous system with learning. Measurements have been made with a variety of techniques (e.g. neurophysiological mapping after craniotomies, electroencephalography, magnetic source imaging, functional magnetic resonance imaging, electromyography, cortical response mapping with positron emission tomography, spectroscopy and neurochemical analysis of neurotransmitters, growth hormones, inhibitors, corticosteroids). With learning:

1. The distributed cortical representations of inputs and brain actions “specialize” in their representations of behaviorally important inputs and actions for skill learning
2. Important behavioral conditions must be met in the learning phase of plasticity that enable growth in the number of neuron populations excited, progressively greater specificity in the neuronal representations, and progressively stronger temporal coordination
3. The selection of behaviorally important inputs is a product of strengthening input-coincidence–based connections (synapses)
4. Cortical plasticity processes in child development represent progressive, multiple-staged skill learning
5. Cortical field-specific differences in input sources, distributions, and time-structured inputs create different representational structures.
6. Temporal dimensions of behaviorally important inputs influence representational “specialization.”
7. Integration time “processing time” in the cortex is enhanced with training.

(C) Effective learning based sensory and motor training is associated with:
1. Increased area of representation
2. Smaller receptive fields
3. Increased density of receptive fields
4. Improved organization
5. Improved order of representation
6. Increased myelination
7. Increased complexity of dendrites
8. Increased strength (amplitude) of evoked responses
9. Decreased latency of response
10. Increased consistency of response (e.g., density of neuronal response)
11. Improved selective excitation
12. Improved autogenic and surround inhibition
13. Improved neurochemical transmission
14. Normalized location/translocation
15. Normalized pattern of response
16. Increased interconnectedness
17. Spread of healthy neurons to take over function in areas where damage occurred
18. Early achievement of developmental milestones
19. Increased specificity of neuronal firing
20. Improved synchrony of neuronal firing
21. Spatial representational mapping consistent with coincident temporal events
22. Increased salience of neuronal responses
23. Increased interrelatedness of temporally related neuronal firing
24. Change in number and complexity of synapses
25. Improved resistance to representational degradation

(D) We also know that plasticity is not infinite. There are constraints that limit the magnitude of plasticity, for example there are:
1. Competitive processes between plasticity pathways
2. Spreads of anatomical sources and convergent–divergent inputs
3. Limitations of time constants governing coincident input co-selection
4. Achievable coherences of extrinsic and intrinsic cortical input sources
5. Top-down organizational influences on cortical representational plasticity

(E) Basic science and clinical research studies report positive correlations between functional outcomes and neural adaptation. With timely prevention, appropriate management of acute insults to the CNS, spontaneous recovery, and thoughtful attention to activities of daily living, excessive CNS problems are
minimized. Further, medications and rest immediately post injury prevent more extensive damage to the brain, rehabilitation can lead to powerful learning based mechanism to drive more complete recovery of function. Changes in neural adaptation can be measured clinically in terms of improvement in:

1. Fine and gross motor coordination
2. Sensory discrimination
3. Balance and postural control
4. Reaction time
5. Accuracy of movements
6. Rhythm and timing of movements
7. Memory storage, organization, and retrieval
8. Alertness and attention
9. Sequencing
10. Logic, complexity, and sophistication of problem solving
11. Language skills (verbal and nonverbal)
12. Interpersonal communication
13. Sense of well-being
14. Insight
15. Self-confidence
16. Self-image
17. Signal/noise detection; able to make finer distinctions
18. Ability to “chunk” information for memory and use
19. Learning skills including faster learning
20. Achievement of developmental milestones
21. Sensitivity of the nervous system with reduction in hyperactivity and sensory defensiveness
22. Ability to perform a skill from memory
23. Flexible behaviors; variability in task performance
24. Flexibility for experience-based learning

The brain is a learning machine that adapts across the life span base on development, injury, aging and learning based training that meets specific criteria: attended, repetitive, progressed in difficulty, rewarded and spaced over time. Learning modifies structure and function.
Neuromusculoskeletal examination

On the musculoskeletal examination, the patient may complain of weakness, but the muscles are usually strong unless there are signs of clear peripheral nerve compression with secondary atrophy (e.g. thoracic outlet, cubital tunnel, carpal tunnel). However, there may be an imbalance in strength with the extrinsic muscles serving the hand compared to the intrinsic muscles, the small muscles that originate and insert inside the hand (Byl et al., 1996). Poor posture is common (forward head and shoulders) and there may also be end range limitations in finger spread, forearm rotation or shoulder external rotation (Wilson et al., 1993).

The neurological examination should be normal (e.g. normal tendon reflexes, good coordination, stable gait, normal light touch) with some complaints of ulnar neuropathy but with normal nerve conduction (Charness, 1993). However, some individuals note a worsening of normal physiological tremors, uncontrollable excitability, and maybe even some dullness in the pads of the fingers when placed on the target surface. These patients may also perform poorly on tasks demanding cortical sensory discrimination (e.g. stereognosis or graphesthesia) (Byl et al., 1996).

During the examination, it is critical to look for the abnormal movements when the patient performs the target task. This is the most objective

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<th>Table 2</th>
<th>Goals for learning based sensorimotor retraining.</th>
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<tr>
<td>1. Think positively about recovery</td>
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<td>2. Stop the abnormal movements</td>
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<td>3. Create a positive environment that meets the requisites for learning</td>
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<td>4. Teach the patient to be their best therapist</td>
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<td>5. Develop normal hand biomechanics and good ergonomics (integrate graded, stress-free patterns of movements)</td>
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<td>6. Quiet the nervous system (decrease hypersensitivity of muscle spindles, deep tendon reflexes, autonomic responses)</td>
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<td>7. Re-differentiate the cortical representations with good sensorimotor feedback</td>
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<td>8. Restore normal graded motor movements</td>
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<td>9. Restore the ability to perform normal, slow, fine motor movements using the small muscles in the hand</td>
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<td>10. Learn to perform nontarget tasks that are similar to the target task</td>
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<td>11. Learn to perform target tasks, beginning with components of the task that can be done normally and then progress to full task</td>
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<td>12. Return to preferred work</td>
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The goals for training are multifactorial and must be individualized for each individual patient.

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<th>Table 3</th>
<th>Set a positive foundation for retraining.</th>
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<tr>
<td><strong>Establish a positive health and wellness program</strong></td>
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<tr>
<td>• Good postural alignment with gravity</td>
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<td>• Normal postural righting reflexes and balance</td>
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<td>• Adequate length and mobility of musculoskeletal system</td>
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<td>• Maintain normal excursion of neurovascular tissues</td>
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<td>• Develop a stable pelvis (hip abductors) and strong lower abdominal muscles</td>
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<td>• Keep neck muscles relaxed (especially scalenes)</td>
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<td>• Breath diaphragmatically</td>
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<td>• Maintain good hydration (8–10 glasses of water per day)</td>
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<td>• Eat a healthy diet</td>
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<tr>
<td>• Get adequate sleep (7–10 h/day)</td>
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<tr>
<td>• Manage stress and anxiety (workplace/ personal)</td>
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<tr>
<td>• Think positively about learning</td>
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<td>• Avoid autonomic responses (fight/flight, cold hands)</td>
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<td>• Build self esteem and self confidence</td>
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<tr>
<td>• Participate in regular exercise 4 times per week</td>
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<tr>
<td>• General aerobic exercise program</td>
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<td>• Supplement with movement awareness training</td>
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To maximize learning, subjects must create a positive learning environment addressing external environmental conditions and internal, personal characteristics with health and wellness the basic foundation.
validation of FHd. Patients should be videotaped while performing the target task with movements scored for quality and severity. The Arm Dystonia Scale can be used for rating the severity of the dystonia (Fahn et al., 2004; Tubiana, 1998). Some clinicians may be able to use computer technology or electromyography to objectively document abnormalities of timing and force (Pascual-Leone et al., 1995; Wilson et al., 1991). It is important to examine the involved and uninvolved limbs (Charness, 1993; Byl et al., 1996a,b; Byl and McKenzie, 2000; Chen and Hallett, 1998; Fry, 1986; Leijnse, 1997; McKenzie et al., 2003; Wilson et al., 1993; Tinazzi et al., 1999).

While not commonly ordered in the clinical setting, research studies use functional magnetic resonance imaging, electroencephalography and magnetoencephalography (Roberts et al., 1995) to document differences in neural firing patterns, blood flow patterns with task performance, and representational topography such as representational size, location, digit spread and order (Elbert et al., 1994, 1995, 1997; Chen and Hallett, 1998; Peterson and Merzenich, 1995; Tinazzi et al., 1999; Byl and McKenzie, 2002; Byl et al., 2002). It is also possible to use biofeedback to measure involuntary co-contractions of agonists and antagonists, prolonged firing and inability to maintain consistent firing of the dystonic muscles against resistance.

Focal hand dystonia (FHd): general conservative treatment approaches

To date, there are no intervention strategies that are 100% effective for restoring normal motor control in patients with FHd. Botulinum toxin injections or Baclophen can decrease the severity of dystonic cramping by interfering with neural signals to the muscle (Brin et al., 1987; Fahn and Marsden, 1987; Tsui et al., 1993; Karp et al., 1994; Ceballos-Baumann et al., 1995; Cole et al., 1995; Pullman et al., 1996; van Hilten et al., 2000). However, these treatment strategies should be paired with retraining.

Surgery such as nerve decompression at the elbow or wrist may be helpful even if the nerve conduction is normal (Charness et al., 1996). Surgical release of tight retinaculum or fascia has been tried with limited success. Surgical implantation of deep brain stimulators is not commonly used for patients with FHd. None of the medications or surgical strategies actually target the defined somatosensory degradation.

Conservative exercise strategies based on the principles of neuroplasticity have been tried as

Table 4 Set up a regular program of supervised training.

- Educate patients regarding the plasticity of the nervous system and requisites for retraining
- Arrange supervised PT appointments to teach patients the principles of progressive task practice
- Outline a strategy for how the patients begin their rehabilitation program with the understanding how to progress their practice
  - Discuss learning tasks with the unaffected side first
  - Discuss the principles of imagery if necessary to assist in being able to perform a task normally
- Provide the patient a home program in writing and review it
- Give patients examples of activities where they can learn something new every day
- Develop a log sheet for patients to use to keep track of what they do at home
- Give patients a phone number or an email where they can contact the therapist to report progress or ask questions
- Where possible, find patients who would be willing to talk with others about their recovery

The patient must become their own best therapist, committed to a home program with appropriate documentation of activities supplemented with supervised sessions with the health care team for education, clarification of goals, and instructions for how to repeat and progress activities.
Table 5  Principles of biomechanical stress-free hand techniques.

It is important for patients to learn how to use their hands in a healthy functional position, taking advantage of the balance of the muscles and structure of the hand. These instructions are supplemented with pictures to help patients visualize the activity. If a patient has had a stroke or head injury or has cognitive problems, then pictures should be given to the patient to support written instructions. A videotape of the tasks to be practiced can also be helpful.

(A) General principles of retraining stress-free hand use
1. Emphasize sensory input and feedback when performing a functional task (e.g. put sticky, coarse or rough surfaces on your tools (e.g. pen, keyboard, glass, hammer, utensils))
2. Break down each task into easy, manageable components that can be performed normally without abnormal movements, pain or strain (e.g. practice picking up and putting down the pen with minimal force before beginning to write with the pen)
3. Perform each part of the task without abnormal movements, pain or strain (e.g. no unnecessary extraneous movements, no overflow of movements to other limbs, to involuntary abnormal patterns of movement like bending of the wrist with bending of the fingers, no excessive muscle activation)
4. Be sure that each activity requires attention, repetition, progression of difficulty, feedback regarding accuracy of performance and positive reinforcement (reward)

(B) Maximizing good biomechanics of the hand
1. Maintain the natural arches of the hand in all functional activities (hand should look round)
2. Strengthen the small muscles inside the hand (intrinsic muscles) to facilitate stability of the hand
   (a) Spread the fingers apart against resistance of a rubber band (try not to use the muscles that straighten the fingers)
   (b) Pinch the fingers pads of the fingers together by holding a piece of paper between your fingers. Use your other hand to pull the paper out or use the other hand to try to open the fingers
   (c) Bend the large knuckle of the fingers to 90 degrees (metacarpophalangeal joint) and keep the fingers straight
      (1) Place the back of the hand against the edge of a table with the MP joint at 90°
      (2) Try to keep the fingers straight while using your other hand to try to bend the fingers (all together or one at a time)
3. Concentrate on using the small muscles of the hands by using a light precision grip in all functional activities
   3(a) Keep the fingers straight or slightly bent and bend the fingers from the base joint (the large metacarpophalangeal joint that joins the finger to the palm) and keep the distal part of the fingers straight or slightly bent and then
      ● Bring the thumb to the pad of the index finger
      ● Bring the thumb to all finger pads
      ● Put the thumb and all of the finger pads around a spherical object
   3(b) Avoid heavy gripping of the hand in a power grip; only squeeze the fingers in a power grip when it is necessary
      ● Do not squeeze the steering wheel
      ● Avoid aerobic or strengthening exercises that require a power grip
      ● Do not work on strengthen the power grip
3(c) Avoid using the key grip (thumb to side of the index finger)
- This puts strain on the base of the thumb (metacarpal phalangeal joint)
- Pad the heads of your keys to minimize the stress of turning the key using the key grip

3(d) Practice reaching for common objects with the eyes closed and the hand relaxed; let the sensation of the surface of the object open the hand. Example:
- When you reach for your cup, let the cup open the hand (e.g., do not actively spread the fingers open first)
- Do not use the handle of a cup but rather let the whole cup slip into your hand
- Drop your hand onto a piano keyboard and let the keys open the hand; do not actively spread the fingers

3(e) When using an instrument or a tool, let the sensation of the object teach your hand to provide the force needed
- Modify the sensation of the object by placing a rough surface on it
- Take a practice lift of the object to determine how heavy the object is
- Practice manipulating the object with the eyes closed

4. Avoid aggressive, rapid, alternating, forceful finger flexion and extension movements of the fingers

5. Transfer some of the work of the hand from the fingers to the forearm. For example:
- Lift the fingers by rotating the forearm into supination (e.g., turn palm up). If forearm rotation is limited, let the shoulder externally rotate if necessary
- When the palm needs to be down and the forearm feels tight, let the elbow swing away from the trunk if necessary to keep the hand. Use the hand in natural functional positions
- Keep palm round from the base of the thumb to the end of each finger
- Palm should be round from the thumb to the little finger
- All of the finger joints should be slightly bent
- Keep wrist extended about 15°
- Hand should look relaxed like it does when it is hanging at your side
- Let all fingers rest down when using the hand on a keyboard or musical instrument
- When use one digit (e.g., on a keyboard), press down using the muscles inside the hand and then release without actually lifting up (extending the digit)

6. Do not let the joints of the fingers collapse or excessively extend when they are down on a surface (e.g., this may be difficult if the joints are hypermobile or the muscles inside the hand are weak)
- Practice dropping the hand onto a surface and maintaining the roundness of the hand
- Put your hand on a flat surface with a small ball in the palm; lean lightly onto the and keep the hand round
- Thread the fingers of one hand through the fingers of the other hand to help stabilize the hand when placing weight onto the hand, as in 2
- Put a soft, firm rubber ball about 2 in in diameter on the table; roll the palm of the hand over the ball while letting the finger pads (not the tips) drop onto the surface

Patients must learn the natural biomechanics of the hand including how to use the hands in a functional, normal position with minimal abnormal force, stress or end range posturing: (A) general principles of biomechanics; (B) maximizing good biomechanics of the hand (Byl and McKenzie, 2000).
Table 6 Specific learning based sensorimotor training.

(A) Instructions for sensorimotor training
Retraining the brain will require a high level of attention and commitment. Abnormal movements must be stopped. Tasks must be performed normally and progressed in difficulty. If it is not possible to move normally, it may be necessary to begin your training with mental imagery rather than task practice. Focus on the sensory aspects of using your hand, not the motor aspects. When you can imagine performing the tasks normally, begin by practicing very simple movements with the affected hand. Begin to practice on nontarget tasks. Think positively about getting better. Biofeedback may be helpful to try and become more in touch with excessive muscle recruitment. It will be important to try to prevent the firing of the muscles that bend your joints at the same time as the muscles that extend your joints. We do not know exactly how many learning based repetitions are needed to re-differentiate the hand sufficiently to restore normal motor control. It will be easier to do learning based retraining if you do not have to continue to perform the target task abnormally as part of your work.

(B) Preliminary activities to improve readiness for learning based sensorimotor discrimination training
1. Restore recognition of hand laterality
   (a) Follow the guidelines developed by Moseley (2005) for retraining laterality and positioning of the hand
   (b) Present pictures of the hand in different orientations and different positions of the wrist and fingers and identify if right or left
   (c) Present the pictures in random order, faster and faster and be able to accurately determine the side
2. Restore ability to mentally imagine putting the affected hand into different positions (Mosely, 2005 as above)
   (a) Show pictures of the appropriate hand (affected) in different positions
   (b) When picture is shown, mentally put your hand into the same position as the one in the picture
   (c) Practice doing this while changing the order of the positions and the time the position is visualized
3. Restore the ability to imagine performing normal movements while observing a videotape of the hands of someone else performing target and nontarget tasks
   (a) Videotape different people performing target and nontarget tasks
   (b) Watch the videotapes and imagine that the hands being observed are your hands performing the tasks without pain or abnormal movements
4. Restore the ability to copy a mirror image of the affected side (see Ramachandran reference, Mosely reference, Byl references)
   (a) Place the unaffected hand in front of a vertical mirror and the affected hand behind the mirror (out of site)
   (b) Look in the mirror and note that the mirror image of the unaffected hand looks like the affected hand
   (c) Do simple tasks using the mirror image to guide the movement of the affected side
      (1) Take the pictures from the visualization training and assume the position of the hand wrist (Mosely, 2005)
      (2) Do simple functional tasks with both hands simultaneously (e.g. turn hand up/down, tap a finger, bring thumb to each finger, pick up a pen, circle the pen, pick up objects of different size or same size but different surfaces) (Byl)

References:

(C) Progressing learning based sensorimotor training
1. Retrain touch, muscle and joint receptors at nontarget tasks
   (a) Develop a variety of active sensory discrimination activities you can do by yourself (e.g. actively exploring to interpret different object surfaces—stereognosis)
      (1) Take the opportunity to feel objects in your environment and identify the objects without looking at the object
      (2) Put small objects in bowls of rice or beans and reach in and try to find and match the objects
      (3) Hang different objects from a string attached to a door jam; start the objects swinging and allow them to stimulate across your hand. See if you can differentiate the different objects as they move across your hand
(b) Modify the difficulty of the sensory task
   (1) Change the intensity of the sensory stimuli (e.g. make the surfaces less distinct)
   (2) Increase the challenge or the complexity of the stimuli you are trying to identify
   (3) Change the environment in which you are exploring the sensory stimuli (e.g. hand in water, still or agitated, in shaving soap, in whipping cream as discriminate an object or manipulate a pen)
   (4) Change the position you assume when discriminating the stimulus (e.g. lie down on your back or your stomach, stand instead of sitting)
(c) Palpate objects in water or other media for identification; have the water be still and then agitate the water so it is harder)
(d) Put pairs of coins and objects in your pocket (or a plastic bag) and try to match them or discriminate between them
(e) Purchase clay that can be molded and shaped and then heated until firm
   (1) Place or draw different shapes on the clay
   (2) Always include a pair of designs that can be matched
(f) Paste matched pairs of items on a card and try to find the matched pairs
   (1) Paste stickers with shapes on cards and try to find matched pairs
   (2) Paste matched pairs of buttons on a card
   (3) Paste alphabet soup letters on a card and match letters or spell words
   (4) Put magnetic letters and other shapes on a card or a refrigerator and move to spell words
(g) Take construction paper and create pairs of letters, shapes, or other designs by pressing heavily with the pen; this will create a raised surface on the other side
   (1) With eyes closed, palpate and try to find matching pairs
   (2) Turn the paper in different directions to make the exploration different
(h) Make a grab bag of items and have patient reach into the bag and identify by gentle touch
(i) Obtain Braille workbooks and learn to read Braille
   (1) If you have trouble learning Braille with the affected side, try with the unaffected side
   (2) Do not tense your hand as you feel the letters and do not extend the adjacent digits away
   (3) Work your hands smoothly over the dots. You can improve your skill, getting other workbooks for the blind and ultimately purchasing books in Braille
   (4) Obtain "Braille object cards" where the object is described in Braille. Palpate the letters and sentences
(j) Place raised numbers and designs on the computer keyboard and try to determine what the number/shape is before striking the key; make some labeled letter match or mismatch the key itself

2. Practice activities requiring the interpretation of sensory information delivered to the skin (interpretation of sensory inputs without active exploration of the stimulus—graphesthesia)
   (a) Ask a friend to stimulate your skin with different stimuli (e.g. hot, cold, sharp, dull, rough) and try to identify the stimuli
   (b) Ask this friend to draw numbers, letters, words (upper and lower case or cursive) and designs on your forearm, hands and fingers when you are not looking
      (1) Identify the letters/numbers/words/shapes verbally (e.g. start with capital letters)
      (2) When it is easy to be correct on capital letters, have your friend draw lower case letters including words
      (3) Progress to having designs drawn on your skin; replicate the design by drawing it on a piece of paper or on your own skin on a piece of paper
         (a) Ask your friend to give you feedback about the drawing to make sure the drawing matches the stimulus (e.g. angles, detection of curves, spatial orientation, size, extra lines)
         (b) Have your friend repeat the design 2–3 timex until it is correct (either making it bigger or finally demonstrating the design while you look at it)
         (c) Progress difficulty by making the drawing smaller (e.g. 2–3 mm) and then more complicated
   (c) Progress difficulty by making the drawing smaller (e.g. 2–3 mm) and then more complicated

3. Use other stimuli to reinforce somatosensory learning
   (a) Develop tasks to improve sound discrimination (either location or determination if heard one or two sounds delivered
   (b) Provide a visual stimuli at the same time the object is touched to the skin to provide a somatosensory stimulus (on the affected and unaffected side); the goals is for the subject to accurately describe the cutaneous stimulus (e.g. sharp, dull, smooth, rough, silky, hard, soft)
Table 6. (continued)

4. Develop activities to emphasize proprioceptive/kinesthetic learning
   (a) Where necessary use tape on the skin, electrical or auditory biofeedback or put weights around the wrist and ankle to increase feedback from joint, tendon,
       and muscle receptors
   (b) Create games in which a part of an object has to be accurately placed a topographical picture (omit has to be placed on the right place on a picture or on an
       object)
   (c) Create games in which objects have to be moved accurately across specific distances on a variable surface
   (d) Create objects of the same weight and place different types of surfaces on the object (e.g. Velcro, sandpaper, flooring). Then practice picking up, moving
       and putting down the object with minimal effort
   (e) Assemble puzzles by feeling the matching pieces rather than looking with your eyes closed
   (f) Work with a friend and practice copying movements together (first by looking and then by feeling)
       1. Tap one finger while others are resting down
       2. Bring arms up over head and tap one finger at a time
       3. Bend wrist with one hand and bend elbow with other arm
       4. Circle wrist to the right (right hand) and circle to the left with left hand
   (g) Have a friend give you some resistance as you move one finger, the wrist or the forearm up and down
   (h) On a piece of paper, draw hand diagrams with different angles of each finger and different angles of the wrist. Then put up a vertical screen where you
       cannot see your hand. Look at each picture and try to copy the pictures with your fingers. Look behind the screen to check to see how accurate you are
   (i) See if you can rent a continuous passive motion machine
       1. Set the machine at different speeds
       2. Try to follow the movements of the machine
       3. Vibrate on the skin over the joint in the direction opposite to the movement
       4. Carefully time the movements to enable the trainee to be successful
   (j) Practice grasping objects with a very light grip on the object. Use a spherical group (thumb pad to the pads of other fingers) Practice this with objects of
       different size with minimum graded force
   (k) Practice bending and straightening your elbow, wrist or fingers while vibrating at the appropriate joint
       1. When bending (flexing) the joint, vibrate on the extensor surface
       2. When straightening the joint, vibrate on the flexor surface

(D) Practicing, sensory and fine motor activities at nontarget tasks
   1. Move smoothly and slowly in normal patterns in desired directions without excessive firing of the muscles
      (a) Consider a number of strategies to allow you to move the most difficult finger most easily (e.g. stabilize adjacent digits)
         1. Use a soft splint to stabilize the fingers adjacent to the finger you want to move
         2. Mold a piece of clay and keep an area clear under the finger you want to move and place a hole in the clay for the other fingers to rest in
         3. Put a buddy strap on fingers adjacent to dystonic or painful finger
         4. Use an interphalangeal splint on fingers adjacent to dystonic fingers
      (b) Increase sensory feedback on the finger you are trying to move (e.g. use tape on the finger)
   2. Play games with the eyes closed that require discrimination of sensory information through the skin of the fingers
      (a) Play dominoes
      (b) Play pick-up sticks
      (c) Play shape games (e.g. match a shape to an opening such as perfection)
      (d) Put together puzzles that have a raised surface
      (e) Play Scrabble with raised or indented letters
(f) Play games that require orientation in place without the benefit of vision
   (1) Play pin the tail on the donkey
   (2) Walk through the house with your eyes closed and hands out to feel objects in your way and to catch yourself if needed
   (g) Get a Braille deck of cards and play cards (e.g. solitaire can be played alone or play hearts, bridge, pinnacle or poker with others)
   (h) Create other sensory games that require planning and control and can be done without vision

3. Practice using objects to do normal functional tasks
   (a) Feel objects and then define what the object does and then demonstrate how to use the object accurately and smoothly
   (b) Have a friend provide a sensory stimulus and ask you to do something that indicates you felt the stimulus (e.g. when I tap with this sharp object, I want you to tap once, but when I touch you with this dull object, I want you to tap twice’’)
   (c) Feel a number of items in a bag that are related to performing a task and put the items together to do the task
   (d) Feel a number of objects put together in a specific design; give the patient a second set of the objects to replicate the or match the design
   (e) Practice throwing objects of different size; practice throwing them to a particular spot
   (f) Get accustomed to grading movements without uncontrollable contractions
      (1) Place the hand on a moving target and do not stop the movement
      (2) Manipulate objects without excessive force
      (3) Put hand on a record player and do not stop the record movement (e.g. do not change the sound)
      (4) Put hand on a treadmill and feel the moving belt
         (a) feel the belt moving under the hand
         (b) hold objects under the fingers
         (c) pass objects back and forth between the hands and make the objects feel the same
   (g) When it is possible to perform the sensory activities in nontarget tasks, begin placing hand on target instrument without abnormal movements
      (1) With the hand on the target instrument, mentally rehearse the movements and the tasks you should perform
      (2) Add rough surfaces to the target instrument if necessary to change the interface with the hand (e.g. sandpaper, sticky paper)

E) Progression of sensory motor and fine motor training at target task
1. Emphasize the sensory aspects of the task even when beginning to perform the target task. Think sensory
2. Perform a selected component of the task (e.g. drop one finger down on the keyboard)
3. Progress the ability to complete more and more of a target task emphasizing sensory exploration as long as the tasks can be done normally
4. Be sure to get reinforcement for performing all activities normally (e.g. use a mirror, use biofeedback, get verbal feedback)
5. Have someone make a video performing the target task that you are having trouble with. Then try to copy the movements. Watch the movements carefully and imagine that the movements are your hands moving
6. Perform the target task in different, nontraditional positions (e.g. practice in nontraditional positions like lying on your back, lying on your stomach, reaching hand behind you or over your head)
7. Do the target task in different media (e.g. if having a problem with writing, draw shapes and letters in shaving soap; draw big letters and then small letters and then words)
8. Provide external support of the affected hand to appropriately position the digits (e.g. a splint if necessary to prevent movement of adjacent digits) while doing sensory and sensory motor tasks on the target instrument
   (a) Begin with a single digit adjacent to the most involved digit, but not the most involved digit
   (b) When can do complex sensory exploration with a single finger without abnormal movement, combine sensory exploration with more complete target movements
   (c) Add multiple digits to the sensory motor tasks
9. Without externally supporting the position of the digits (e.g. all digits free) perform one simple movement on the target task
   (a) Integrate sensory exploration with the simple movements and do the movements slowly to a metronome
   (b) Increase the complexity of the sensory driven motor tasks (e.g. tapping single note to playing scales and chord to playing new music or new keyboard tasks)
(c) Increase the speed of the movements on the target task, keeping up with the metronome
(d) Perform target task normally for very brief periods of time and progress the practice time slowly with frequent breaks
(F) Reinforcing sensorimotor learning with feedback
1. Biofeedback can include visual, cutaneous, muscle, vibration, auditory or stretch stimuli
2. Biofeedback can be supervised by another person, facilitated with robotic movements, controlled by electronic contraction (activation of muscles), controlled by a physical constraint of a limb, guided repetitive passive movements supplemented with active movements to control motor output
(a) Put tape on the top of the skin over the extensor surface of the digits to limit motion or emphasize somatosensory input and feedback
(b) Use multichannel biofeedback to teach patients how to avoid abnormal movement strategies
   (1) Practice isolated movements and stop practice if you create unnecessary co-contractions of agonists and antagonists
   (2) Use the small muscles inside the hand (intrinsic muscles) to movement the digits instead of extrinsic muscles
3. Use imagery, mental rehearsal, and mental practice to restore normal hand representation and normal motor control
(a) It is important to be able to restore the normal image of the involved limb; that is how it used to be and how it will be again. In the process of restoring normal control, it is also important to begin to use the hand normally and not increase the pain or repeat the abnormal movements
   (1) Visually imagine your hand and how it looks. Making your hand look like the other hand is a good beginning
   (2) After you can successfully visually image your hand working normally, begin to create a motor image of the hand and the task you want to perform (omit-in which you begin to). Imagine using the hand (omit-it) normally to perform all of the usual and target tasks
   (3) Begin imaging the performance of functional tasks by only imaging small parts of a larger task and then finally the whole task and then related skills and activities that would go along with the task
(b) The evidence is increasing that imaging recruits the neurons in the motor and sensory cortex as well as the prefrontal and supplemental motor cortex. Imaging also leads to firing of neurons required to perform specific well learned functions (e.g. writing, playing an instrument, riding a bike)
   (1) When you image performing a given task, you recruit the sensory and motor areas of the brain that represent the part of your body you are using as well as the functional part of the brain activated for the that task
   (2) When you visually image a body part, you will activate the part of your brain devoted to vision (e.g. occipital lobe). When you imagine actually doing the task (motor imagery), you will also activate the motor cortex. When you imagine how it feels to do a task, you will activate the somatosensory cortex
   (3) Try to imagine performing your tasks without mistakes. This will reinforce the positive aspects of the sensorimotor feedback
(c) Set a time each day for relaxation and imagery; avoid interruptions
4. Some people find it helpful to purchase audiotapes, or videotapes to walk you through the imagery process. Imagine a sense of fitness, wellness, well being and overall independence and control
5. Begin imagery by going back in time where you can imagine your hand was normal
6. Set specific goals for yourself. Imagine the steps you need to accomplish to improve the function of your hand (be specific in terms of how it looks, feels, and moves) and then define progressive tasks you will mentally practice
7. Assess your own emotional state and try to reduce stress and any barriers that could get in your way
8. Even when your hand has returned to normal, remember to continue to do mental practice to reinforce physical practice

Learning based sensorimotor training must be progressed in an orderly way without eliciting abnormal movements (see A–G). The activities will be matched for each individual patient. The emphasis is on progression using normal movements driven repetitively to facilitate neurochemical, cellular, myelination, and dendritic connections to produce desirable functional gains: (A) general instructions; (B) improve readiness for learning; (C) progressing training; (D) practicing nontarget tasks; (E) practicing target tasks; (F) reinforcement and feedback.
alternative or supplementary medications and surgery. Some of these learning paradigms include

- constraint induced therapy (also called sensory motor retuning) (Candia et al., 1999, 2002, 2003),
- sensitivity training (Tubiana, 2003), conditioning techniques (Livermedge, 1960),
- kinematic training (Mai and Margiardt, 1994),
- immobilization (Priori et al., 2001) and
- learning based sensorimotor training (Byl et al., 2000a, b; Byl and McKenzie, 2000).

While single case design studies and planned experimental studies have been carried out on these techniques, none of these strategies have been confirmed by randomized clinical trials. The strongest validation for learning based behavioral training for the treatment of FHD is based on basic science evidence that the central nervous system is adaptable and FHD is associated with a degradation of the topographical representation on the cortex. The principles of neural adaptation must be applied to intervention strategies (see Table 1). Learning based sensorimotor training is one application of these principles for treating patients with FHD.

Specific learning based sensorimotor training: one treatment approach for FHD

The goals of learning based sensorimotor training are listed in Table 2. It is critical for the patient to be able to stop the abnormal movements of the upper limb. These training activities need to take place in a positive environment for learning (see Table 3).

The physician, the therapist, the patient and the family need to work as a team. The patient, the family and the team must have positive expectations for the patient to improve. The patient must be willing to come for supervised visits but also become their best therapist and work very hard at home. The program must begin with education, then a schedule of supervised visits is needed before the patient can be expected to manage the home program more independently (see Table 4).

A critical component of getting better is to retrain the brain, particularly the way the hand and involved limb are represented on the cortex (see Fig. 1). The primary focus of the initial supervised sessions (1.5 h) is to set the stage for progressive learning. The patient needs to learn how to use both hands in a stress free way (see Tables 5A–B).

The patient then needs to begin to learn about how to progress learning based sensorimotor training (see Table 6A–F). If it is impossible to perform the target tasks normally, then the patient needs to begin with imagery and mental practice to try and recover functional sensory representation and normal movement. Imagery can be mental or it can be enhanced by mirror images or by video demonstrations of someone else performing the task. The attended, learning based repetitions required cannot be handled only under supervised training. The patient and the family must be committed to stopping the abnormal movements and proceeding with progressive learning based sensory, sensorimotor training at home.

Note

Part 2 of this paper will appear in the next issue of JBMT.

References


Altenmueller, E., Schurmann, K., et al., 2002. Hits to the left, flops to the right: different emotions during listening to music are reflected in cortical laterlalisation patterns. Neuropsychologia 40 (13), 2242–2256.


Aberrant learning in individuals who perform repetitive skilled hand movements


keyboard and other instrumentalists. Medical Problems of Performing Artists 10, 140–146.


Stryker, M., Jenkins, W.M., Merzenich, M.M., 1987. Anesthetic state does not affect the map of the hand representation within are 3b somatosensory cortex in owl monkeys. Journal of Comparative Neurology 258, 297–303.


Woolsey, C., 1958. Organization of Somatic Sensory and Motor Areas of the Cerebral Cortex. University of Wisconsin Press, Madison, WI.


