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Review Article

When Excessive Repetition Interferes with Target Specific Motor Control of the Hand: Do Behavioral Brain Retraining Strategies Facilitate Functional Recovery from Focal Hand Dystonia?

Nancy N Byl*

Department of Physical Therapy and Rehabilitation Science, Professor and Chair Emeritus, University of California, San Francisco, USA

Abstract

Stressful intensive, repetitive practice of precision movements can lead to inflammation, pain or task specific, involuntary hand movements referred to as Focal Hand Dystonia (FHD). The purpose of this manuscript is to provide a review of the theoretical and research evidence regarding the effectiveness of rehabilitating patients with FHD. Current constructs on the etiology of FHD, strategies for priming the nervous system to learn, brain retraining schemes and effectiveness of behavioral rehabilitation strategies based on the principles of neuroplasticity are reviewed. Effective rehabilitation of patients with FHD must be individualized to each patient and requires a team effort coordinated by a physician with movement disorders expertise. Patients and, ideally families as well as employers, must understand the genetic, neuroanatomical, neurophysiological, biomechanical, psychosocial and behavioral factors underlying FHD. Affected individuals must think positively about recovery, comply with life style recommendations and engage in retraining following the principles of neural adaptation to recover voluntary control of task specific movements. Multi-center, multi-disciplinary, longitudinal research studies are needed to determine the most effective neural, behavioral rehabilitative strategies. While strong evidence supports the benefit of botulinum toxin injections, there is only weak evidence supporting the best behavioral, sensorimotor brain retraining strategies to restore voluntary, task specific motor skills. No intervention strategies can predict 100% recovery. Patients and clinicians both report improvement post brain retraining for FHD without adverse effects.Recovery of voluntary task specific motor control ranges from 60-80%, however, simultaneous,objective, documentation of improvement in motor kinematics in target specific task performance remains a challenge.

Keywords: Behavioral brain retraining; Focal hand dystonia (FHD); Neuroplasticity; Rehabilitation

***Corresponding author:** Nancy N Byl, Department of Physical Therapy and Rehabilitation Science, Professor and Chair Emeritus, University of California, San Francisco, USA, Tel: +1 5107982282; E-mail: Byln@ucsf.edu

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Introduction

Work-Related Musculoskeletal Disorders (WRMSDs) account for a significant proportion of work and recreational injuries. (National Center for Chronic Disease Prevention and Health Promotion 2016) [1]. These injuries most commonly occur amongst individuals working in industrial settings, performing arts, computer programming and competitive sports. Overuse injuries can lead to inflammation of muscles, nerves, joints, and connective tissues. Most individuals with WRMSDs complain of pain, neuromusculoskeletal impairments and work disability [2]. Unfortunately, some people develop dysfunction of movement referred to as focal dystonia [3].

Primary, generalized dystonia is the third most common movement disorder in the United Sates [4,5]. Whereas generalized dystonia commonly has a genetic origin, tends to present early in childhood and may or may not progress, the etiology of Focal Dystonia (FD), particularly Task Specific Focal Dystonia (TSFD),isless well understood [6,7]. In TSFD, there may be genetic risk factors, but the development of the phenotypes usually associated with multifactorial factors [7-13].

Focal Dystonia (FD) is defined as an idiopathic, pathologic, synergistic involuntary abnormal recurrent disorder of movement affecting a body part, a body segment or a specific task [5]. The dystonic movements are described as sustained or intermittent, end range, twisting postures (with and without end range tremors). Excessive excitation and inadequate inhibition lead to involuntary co-contractions of agonists and antagonists (flexors/extensors; internal/external rotators) during voluntary, purposeful movements [5,14-16]. The involuntary movements are usually quiet at rest, activated with voluntary actions, worse with stressand often triggered by a specific object or a target specific task [17]. In most cases, general fine motor skills are preserved at non-target tasks [18-20]. The dystonic movements may be described by the affected body part (e.g. neck [cervical dystonia], hand/arm [hand dystonia], foot [foot dystonia], leg [leg dystonia], trunk [truncal dystonia],eye lids [blepherospasm) or by the affected target specific task (e.g. musician's dystonia, writer's cramp, golfer's yip, runner's dystonia, keyboarder's dystonia, hair dresser's dystonia) [21-31].

While FHD most commonly develops slowly, it can also occur suddenly. Sudden onset has been reported after a specific traumatic event associated with a fracture or a peripheral neuropathy in the upper limb [32-34]. Task Specific Focal Dystonia (TSFD), can also develop after a period of intensive, demanding, practice and repetitive performances (with or without reported pain or persistent inflammation) [35-45].

Prevalence and Incidence

The prevalence and incidence of Focal Dystonia (FD) are difficult to estimate [30]. An estimated 10% of individuals with FD have a family history of a movement disorder [46]. Lim and Altenmüeller [47] reported on 183 cases of Focal Hand Dystonia (FHD) (6.1%) in a sample of 3,000 musicians. The musicians playing woodwind instruments were more likely to develop a FD than other instrumentalists. The musicians who developed signs of FD frequently reported increasing the amount of practice or performance time, changing techniques, playing a new instrument or changing biomechanics due to pain or a nerve injury [26]. Of the musicians developing FD, 83.1% experienced the dystonia in the upper limb,with 96.3% of these individuals reporting dystonia of the hand (FHD). Other professionals (e.g. writer's and athletes) also appear to be at risk [48,49]. Individuals with FD commonly self-report a sensory "trick" to decrease the abnormal, involuntary, hypersensitive movements.

Etiology

In the late 1800's, musician's dystonia was categorized as "psychological" because the dystonia usually developed at a time of stress, often associated with depression [50]. At the time, no objective, abnormal neurophysiological or structural impairments were identified to explain the unusual movement dysfunction. Counseling and medical treatment were generally not effective. Consequently, many of those affected had to give up professional performance [51].

Today, the etiology of FD is still considered idiopathic,with increasing evidence supporting a multi-factorial etiology [18,24,31,36,39-41,46,52]. The contributing factors range from social behavioral characteristics [41,53-56] impairments of structure and biomechanics [10,57] inadequate inhibition [4,58-60], motor impairments [61,62], sensory problems [48,63-71], prior limb trauma [33], peripheral nerve strain [72], aberrant learning [26,73] to compromised homeostatic plasticity [74]. A positive genetic history can increase the risk of developing a focal dystonia [75,76]. Some familial genes have been identified for cervical dystonia [77], but the genes are of low penetrance with signs and symptoms that usually present following environmental, psychological, neurological, mechanical or neurodegenerative stress. While there may be a familial history for FHD in some cases, no specific genes have currently been identified [78].

Disordered topography in sensory, sensorimotor motor, supplemental, motor and pre-motor cortices have been reported in animal and human models of hand dystonia [15,26,48,69,79,80]. Animal studies have documented the development of involuntary movements following excessive repetitive training [73,81-84]. First, signs of local inflammation were observed, spreading bilaterally and then centrally. Eventually, continued repetition led to the loss of precise grasping associated with abnormal cortical firing and degraded sensory, sensorimotor, premotor and motor representations of the trained limb [73,81,82,85]. The question is whether the degraded topography and involuntary movements developed from pre-existing neurophysiological dysfunction from birth, a consequence of aberrant learning [63,79,80] or a result of inadequate "homeostatic" plasticity [69].

The aberrant learning hypothesis proposes negative adaptation of the nervous system based on highly, repetitive sensorimotor activities [86,87]. In controlled behavioral animal studies, excessive repetitive hand squeezing was correlated with a degradation of sensory topography of the involved hand [73,80,88]. Along with task specific involuntary, finger movements, most patients with FHD have decreased sensory discrimination accuracy [26,42,63,89,90].

The homeostatic plasticity hypothesis proposes intense, rapid repetitions exceed the capacity of the nervous system to adapt [74,91]. Rapid firing of sensory and motor neurons reach a plateau in efficiency and the brain can no longer respond to the fast, individual sensory inputs. The topography becomes disorganized and coordinated motor outputs are disrupted [92]. This plasticity not only involves the cortex [74,91] but also the substantia nigra, cerebellum and even the thalamus [93].

Some controlled research studies have reported differences in selective volume and brain activation patterns in patients with FHD compared to healthy controls For example, during performance of coordinated precision movements, patients with FHD have increased volume of the basal ganglia (putamen) [26,44,94] while normal healthy subjects demonstrate decreased gray matter volume in the putamen. During finger tapping, healthy musicians activate neurons in the thalamus and basal ganglia on the ipsilateral side with activation in the premotor cortical area and the cerebellum on the contralateral side [95]. However, in musicians with FHD, minimal ipsilateral activation of neurons in the thalamus and basal ganglia is seen, but simultaneous contralateral activation in the premotor area and the cerebellum is noted [95].

In 2013, Jankowski and researchers studied responses to self-initiated and externally cued sequential finger movements. Comparing 18 patients with task specific FHD with 18 age matched controls, they reported that individuals with FHD demonstrated no differences in the brain activation patterns of sequential finger tasks, but showed reduced brain activation during movement preparation in the left premotor cortex/precentral gyrus for all conditions. In addition, for self-initiated movements, reduced responses were observed in the supplementary motor area, left mid insula and anterior putamen for patients with FHD.These findings support a pathophysiological model of TSFD in which abnormal brain activity occurs prior to movement onset, secondary to disturbed sensorimotor processing and altered neuronal plasticity [96].

In a recent study by Bianchi and researchers [97], imaging differences were measured in patients with FHD and TSFD. Alterations in sensorimotor processing in body affected areas were confirmed (e.g., the hand region in patients with FHD and the laryngeal region for patients with spasmotic dysphonia). In addition, increased gray matter volume was measured in the middle frontal gyrus (e.g., areas of executive control including the capacity to learn, remember and coordinate correct sequences of complex motor tasks). White matter changes were localized to the corticospinal and corticobulbar tracts in patients with TSFD. These changes could represent changes resulting from strenuous motor training.

Some common psycho-behavioral characteristics are seen in patients with FHD [22,41,51,54,98]. While high level musicians are frequently characterized as a perfectionist, those with FHD tend to be perfectionists, perseverative, compulsive, anxious, stressed, phobic and intense [22]. Patients with task specific hand dystonia may also have difficulty with perceptual motor problem solving [99] as well as feedback and reinforcement learning. Clearly, FHD can create a significant challenge to the quality of life [100].

"Ruling in" the Clinical Diagnosis of Focal Hand Dystonia: History and Physical Examination

There are no laboratory or imaging tests to confirm the diagnosis of FHD**.** To rule in the diagnosis, a thorough medical and psychosocial history are needed (e.g., genetic, family, medical, medications, traumatic, social, occupational, cognitive, depression, stress, physical exercise, nutrition, sleep, habits, personality) [18]. The history must be complemented with a thorough physical examination to confirm the presence of dystonic movements [40,101,102] See table 1**.**

Table 1: Ruling in the Diagnosis of Focal Hand Dystonia [101].

Characteristics	Present/ not Present: Comments
The affected motor hand skill is impaired by errors in timing, force, or trajectory with stereo-typical tonic postures (and are absent at rest)	Yes No Comments
The movement dysfunction persists despite resolution of antecedent events (e.g. inflammatory, traumatic, myopathic or neuropathic abnormalities).	Yes No Comments
The abnormal movements arise when the individual initiates an attempt to execute a specific motor skillin a characteristic context	Yes No Comments
The skill loss cannot be explained by lack of practice	Yes No Comments
The degraded skills cause the individual to function at a reduced level of function despite masking strategies	Yes No Comments

The physical examination should include a standardized assessment of the cardiopulmonary, musculoskeletal, and neurological systems. The differential diagnosis for FHD requires ruling out abnormal neurological findings such as pathological reflexes, rigidity, hypertonicity and cognitive deficits which could raise concerns about other neurological problems (e.g., stroke, Parkinson's Disease, Alzheimer's Disease, Multiple Sclerosis, Amyotrophic Lateral Sclerosis, vestibular pathology, infection) [40]. It is also important to evaluate signs of neural tension of the brachial plexus, peripheral neuropathy, central sensitivity and intrinsic muscle weakness. [103]. Patients should be asked to demonstrate "sensory tricks" they employ to improve voluntary motor control or compensate for functional impairments related to weakness, instability, inflexibility, hypermobility, sensory dysfunction or pain.

With permission, at each visit, the clinician should video tape the patient performing the target task in usual and unusual positions. The videos can provide a record of changes over time. Standardized neuromuscular tests should be administered to measure: l) range of motion (noting hypomobility and hypermobility) [103]; 2) strength (calculating the ratio of intrinsic muscle strength to extrinsic muscle strength [63] 3) peripheral neuropathy in the UE [72]; 4) hand size (small, medium or large**)** [104]**;** 5) finger spread [105]; 6) cervical dysfunction and upper extremity motor coordination [106,107]; 7) severity of dystonia (Arm Dystonia Scale, Fahn-Marsden Dystonia Scale, United Dystonia Scale, Global Dystonia Scale, and/or Writer's Dystonia Scale) [108-110]; 8) sympathetic signs [111,112]; 9) accuracy of sensory discrimination (graphesthesia, stereognosis, barognosis, temporal discrimination) [113-119]; 10) pain (Visual Analogue Scale) [120-122]; 11) sensorimotor skills [123]; 12) objective motor analyses; [22,124,125]; 13) functional independence [126]; 14) specific arm function (e.g. DASH) [127]; 15) objective sensory, motor and perceptual motor processing (Positscience.com) [128]. For practitioners with motion analysis equipment in their clinic, objective kinematic analyses of the movement dysfunction before and after treatment may be helpful [22,124,125].

PositScience.com offers an online, objective, sensory-perceptual-motor test battery that can be accessed through Brain HQ (PositScience.com) [128]. The unique subtests include: Time it (Sequential motor tapping: tap as fast as possible between two arrows for 30 secs); Tap it, (sequential motor tapping (for 30 sec); See it (Eye movements with central fixation and peripherally forcing saccadic movements as letters move between a central fixation and the periphery; Spot it, Hear it, Say it for color discrimination (subject clicks the oddball color in a grid). Auditory loudness magnitude is assessed by having a standard tone followed by another tone presented to the patient who uses a slider to say if the tones presented are less or more than the test tone). Voice pitch is measured by having a patient copy/simulate the sound "ahh". Auditory magnitude of loudness is assessed by delivering a standard tone followed by a test tone, with the patient using a slider to indicate if the test tone was the same, louder or quieter than the stimulus.

For patients with writer's cramp, clinicians may also elect to monitor changes in writing (e.g.,a sample of speed, size of letters, consistency of quality). Assessing traditional posture and postural righting responses supplemented with dynamic balance testing such as the Timed up and Go (www.sralab.org/rehabilitation-measures/timed-up-and-go) [129] or the instrumental Timed Up and Go which includes dual tasking (e.g. carrying a glass of water or counting) is also recommended [130]. Having the patient self-report depression (Beck Depression Scale) [131], personality characteristics (e.g. "Type A Personality") [54,132,133], and quality of life conditions (e.g.,Quality of Life, Life Satisfaction Scale) [134,135] may provide helpful insights.

From the history and physical examination, medical and other health professionals should have enough information to" rule in" the diagnosis of FHD [102,136-138]. The diagnosis of FHD can also be "ruled in" if the patient demonstrates critical characteristics of FHD [101] see table 1. Sensitivity and specificity for "ruling in the diagnosis" based on behavioral and movement-based risk factors will ultimately need to be validated by longitudinal research studies.

Some discrepancies in classifying the specificity of the dystonia persist [139]. Recently, a task force and consensus team recommended a new classification scheme [140]. The clinical characteristics include five descriptors: age at onset, body distribution, temporal pattern, coexistence of other movement disorders and other neurological manifestations. See Table 2 [102] a team applied the consensus information and proposed the following diagnostic algorithm for making a clinical diagnosis of limb dystonia.

First, decide if there are patterned and repetitive movements/postures (spontaneous or triggered by motor tasks) of one or more segments of the upper limb (with or without a tremor). If yes, determine if the patient has identified a sensory trick to minimize the abnormal movement. If yes, then it is likely that the diagnosis is a focal dystonia.

Overview of Rehabilitation Goals and Objectives and Therapeutic Approaches

The goals and objectives suggested here are based on the theoretical construct that FHD represents a case of aberrant learning and/or a loss of homeostatic plasticity leading to an imbalance of excitation/ inhibition, poor preparation for movement and involuntary movements when performing selective target tasks. The rehabilitation goals are first to collaborate with a movement disorders specialist who has created an effective medical management plan and rehabilitation team [141]. Then, the rehabilitation team must focus on priming the nervous system to learn [142]. The next logical step is retraining the brain to improve cortical sensory-motor representations and restore voluntary, task specific motor control to enhance quality of life, independence and return to work [143].

Medical and Pharmacological Management

The physician typically determines what additional diagnostic tests are needed, what health care team members are essential and what medications may be helpful [144]. This team will commonly represent a variety of disciplines ranging from physical therapy, occupational therapy, psychology/psychiatry to orthopedic surgery and neurosurgery. Depending on the needs of the patient, the broader team might include an athletic coach, a music teacher, an ergonomist, a stress management trainer, a dance teacher, and possibly an individual who can do hypnosis, neurobiofeedback or non- invasive brain stimulation (e.g., repetitive Transmagnetic Stimulation [rTMS], repetitive Transcranial Direct Current Stimulation [rTDCS]), or Functional Ultrasound Treatment [FUS]).

The patient and the family need to be thoroughly educated about FHD. The coordinating physician usually initiates education which can be elaborated by other team members during therapy sessions. Information should be provided about the etiology of FHD, the goals and objectives of intervention, preparation of the nervous system to learn, current intervention strategies, evidence regarding effectiveness of treatment as well as a review of the principles of neuroplasticity and brain retraining.

Intramuscular injections of botulinum toxin are the standard medical treatment for FHD [141]. The injections are used to block nerve impulses to the dystonic muscles. Some postulate that the injections may not just weaken the dystonic muscles, but also allow the body to try to create new programs of movement [145-147]. Botulinim toxin injections combined with therapy and retraining may improve the recovery of fine motor control [148]. Sometimes, anticholinergic drugs, such as Artane (trihexyphenidyl) can be helpful to facilitate improved communication between brain pathways for muscle control [149]. Oral pharmaceutical interventions (e.g., anxiety medications, muscle relaxants, bachlofen, carbazepine, benzodiazepines, carmadopamine medications, anticonvulsants, phenol injections and even cannaboids) have also been tried as part of the medical management plan of FHD [138,150,151]. Musicians may benefit from taking selective anti-anxiety medications prior to performance (e.g., Propanol), but should not expect a direct effect on the dystonia [152].

In some cases, specific, orthopedic surgical procedures in the hand may be recommended to release fascia, nerve adhesions or correct abnormal anatomical connections [72]. MR guided, focused ultrasound is a novel minimally invasive surgical procedure for the treatment of Parkinson's Disease and focal dystonia [153-155]. In the United States, neither Deep Brain Stimulation (DBS), surgical pallidotomies nor specific types of thaladotomies are commonly performed for FHD. However, in Japan, stereotactic lesioning and ventral-oral thalamotomies have been performed with reported success [156,157].

Priming the Nervous System to Learn: Preparing for Brain Retraining

To maximize the opportunity for brain retraining, the nervous system must be prepared to learn.This is the foundation for brain retraining across neural impairments. In order to prime the nervous system for learning, each patient must have positive expetaitons for recovery and be ready to address spotential barriers to neural receptivity. The neural priming activities include: a) stopping the involuntary abnormal movements; b) quieting the nervous system; c) developing a healthy life style; d) maximizing oxygen delivery to the body (especially the brain); and e) integrating novel strategies to improve the brain's receptivity for learning (e.g. non-invasive brain stimulation, immobilization, fatigue therapy). See Table 3 for a summary of priming strategies to create a foundation for the brain to maximize the capacity to learn.

Table 2: Classifying the Focal Dystonia [108,138,140].

Axis I					
Age at onset	Infancy: Birth to 2 years	Childhood	12 years	Adolescence 13-20 years,	Late adulthood (>40 years).
Affected Areas (with or without leg involvement)	Focal	Segmental	Multifocal	Generalized	Hemidystonia
Clinical Features	Dystonia only	Dystonia with tremor	Dystonia with increased tension (spasticity or rigidity)	Dystonia with weakness	Dystonia with ataxia
Temporal Pattern	Static	Progressive	Variable; paroxysmal	Persistent action -specific	Diurnal
Progression	Specific	Diural	Paroxysmal	Associated features	Co-occuring with other neurological manifestations
Axis II					
Etiology relative to other movement disorders/ neurological conditions.	Degeneration	Structural	Inherited	Acquired	Idiopathic

Table 3: Priming the Nervous System to Learn.

Minimize abnormal, involuntary movements	**Minimize Abnormal Movements** • Repeating abnormal movements more frequently than normal movements, reinforces aberrant learning. • Patients must stop performing the abnormal, involuntary movements most specifically at the target task. • Individuals may need to temporarily integrate sensory tricks to stop the abnormal movements during performance of the target tasks (e.g., wearing a glove, changing the position of the body relative to gravity such as lying down or inverting) or stop performing the target task. • Having individuals learn about neuroscience/neuroplasticity can be helpful with recovery as well as aid in patient compliance [160-163]. • Interactions between individuals who have recovered from focal hand dystonia and those in the early process of retraining maybebe helpful in trying to stop the abnormal movements. • Mental imagery techniques and mental practice may help patients learn to stop the abnormal movements • The patient should try to remember what it was like to perform the target task normally, without pain or abnormal involuntary movements. • If one can imagine performing the task normally or look at a mirror image of the hand performing the target task normally, a blue print or a phantom of the movement is excited in the brain [164-171]. • In general, there is good evidence mental imagery and graded motor imagery can help maintain function, reduce stress, retrain voluntary movement, learn a new skill or modify pain [172-175]. • Mental representation can be reinforced by observing past self-video recordings or watching other hands perform the target specific dystonia task.
Quiet the Nervous System	**Quiet the Nervous System** • Since FHD is characterized by excessive excitation with too little inhibition, one objective is to reduce over excitation and increase inhibition (referred to here as quieting the nervous system) • Excessive excitation may be described as hyperexcitability, sympathetic over reaction or central sensitivity(e.g., the hand may withdraw suddenly with an unexpected touch, the heart may be racing, there may be excessive hand perspiration, the hand pulls into an abnormal posture when the patient thinks about performing the target task or when the palmar surface of the digits contact the target instrument) [111]. • Quieting the nervous system may be achieved with a variety of techniques (e.g., rhythmically rocking, swinging, vibration, meditation, relaxation in a quiet place). • Quieting may also be enhanced by imaging the past when the nervous system was better balanced and the target task could be performed easily and normally. • When relaxed, individuals can improve control of posture and voluntary movements [173-176].
Life Style Modifications	**General** • Patients with FHD must think positively about recovery which includes critically evaluating one's life style. • A positive life style is key to healthy aging, increasing regular immunity, minimizing chronic disease, increasing telomere length and extending longevity of life [161,177,178]. • A healthy lifestyle includes regular and consistent physical exercise, quality nutrition, minimization of alcohol/drugs/smoking, good hydration, effective stress management, safe work ergonomics, adequate quality sleep, and challenging cognitive learning activities. **Stress** • Given stress is common in individuals with FHD, [179] stress management strategies can be helpful and can include simply doing deep breathing to understanding the physiological effects of stress [180] to taking a course on stress management (e.g., mindfulness training). (http://www.soundstrue.com/store/mbsr-course). • Working with a counselor may help individuals reduce anxiety of physical performance, fear or panic or help speed healing, reduce pain, change bad habits and restore function [173,175]. **Nutrition** • A healthy diet can facilitate restoration of healthy inflammatory responses, good healing, more energy and improved delivery of oxygen. • Individuals should eliminate or minimize refined carbohydrates (e.g., refined flour, refined sugar, refined vegetables oils, processed foods) and eat a diet rich in protein, vegetables and fruit [181]. Individuals should only eat when hungry, eat in a calm manner and stop eating when full. Individuals should also try to create intermittent fasting such as extending the interval between meals, particularly extending the time between dinner and breakfast. • Processed foods should be replaced with whole organic produce, meats, fish and healthy fats, [181] [complemented with drinking 8-10 glasses of water (adding more water when caffeine or alcohol is consumed). • In some cases, individuals with dystonia may benefit from eliminating gluten and milk products and taking supplements that are known to be anti-inflammatory [182]. A referral to a functional nutritionist can be helpful. **Sleep** • Sleep is critical for positive health, positive immunity and quality and consolidation of learning [183,184]. • Although some individuals may require minimal sleep, most individuals need 7-8 hours of sleep with a good period of quality, deep sleep facilitated by dining early, relaxing before going to sleep, taking a warm shower before going to bed, reducing caffeine and alcohol before bed, reviewing positive and challenging aspects of the day [185]. **Physical exercise** • Physical exercise is considered the best medicine for positive health. Everyone across the age span needs to participate in a regular, daily exercise program. • Cardiopulmonary exercise 30 minutes, 3-5 x/week should be complemented with strengthening, flexibility, balance and rhythmic/ coordination exercises 2-3 days/week [186-188]. • A regular exercise program is critical for maintaining healthy musculoskeletal structure as well as brain function. • Generally, it is important to stabilize the trunk and maintain good postural alignment for job performance (e.g. posterior neck gliding, scapular stabilization, strong lower abdominal muscles, good strength in hip abductor and extensor muscles, good flexibility both flexion and extension of the spine) [189-191]. • It may also be helpful to have individuals participate in general movement and rhythm classes in person or virtually (e.g. yoga, Pilates, Feldenkrais, Alexander techniques, Spire strategies, Ty Quan Do, Ji Gong, NIA, dance). • Participating in cognitive learning activities is also important, either during aerobic or after physical exercise. **Protect the Nervous System from Overuse and Pain** • Decrease excessive repetitive hand movements, correcting biomechanical instability, integrating good ergonomics into work and recreational activities, minimizing compensatory movements, strengthening weak muscles, increasing mobility in some ases and decreasing hypermobility in other cases [192]. • Manage acute and chronic pain, minimize soft tissue inflammation of muscle, nerve and fascia), improve joint and soft tissue mechanics and maximize neural gliding, particularly of the brachial plexus. • Neural mobilization techniques and deep, diaphragmatic breathing should be integrated into a home exercise program to decrease neural sensitivity and minimize neural tension [193]. **Keep the Brain Alert** • Physical activities should be enriched with cognitive challenges, environmental exploration and novel experiences [194]. • Every day, each individual should try to avoid habitual behaviors, learn something new, have fun, get out of the house, interact with others and be physically active. • Individuals can keep the mind alert by reading, doing crossword puzzles, playing Suduko, putting together jigsaw puzzles, listening and discussing news reports, learning new words (e.g., Wordsmith), as well as engaging in creative activities (e.g. going to museums, taking trips, noticing changes in the environment while walking, doing photography or painting, inviting friends over to play cards, scrabble or dominos) or performing virtual learning games (e.g., tapping, figure identification, visual field exercises, Brain HQ (Positscience.com; Lumocity.com). • Even when alone or isolated to the house, individuals can engage in social as well as learning activities on the computer.
Increasing Systemic Oxygen Delivery	**Remote Ischemic Limb Conditioning (RILC)** • Some evidence exists for correlating regional blood flow and the severity of hand dystonia (writer's cramp) [195]. • The brain needs good delivery of oxygen to learn, with or without FHD. • Besides drinking adequate fluids, other methods of increasing oxygen delivery can be tried. • Intermittent hypoxia followed by increased oxygen delivery can help prime the nervous system (Remote Limb Ischemic Conditioning [RLIC]) [196]. • RLIC has historically been used to prepare patients to be more tolerant of ischemia during heart surgery [197-202].

	• In a controlled animal study, Hahn et al., [203] confirmed RLIC pre or during a surgically induced stroke, reduced the size of the lesion. • In Europe, RLIC is delivered shortly before, during and shortly after an ischemic stroke event to reduce the size of the stroke lesion [204-209]. • More recently, RILC has been associated with increased motor learning and motor control in healthy adults [107,210-215]. • The RLIC protocol [210] used by is simple to follow: 1) use a regular blood pressure cuff; 2) measure resting blood pressure (systolic and diastolic); 3) take cuff pressure to 20 mm above the systolic blood pressure; 4) maintain the pressure for 5 minutes and then release the pressure for 5 minutes; 5) do 5 cycles; 6) do treatment over 7 days. • It may take a few treatments for the patient to accommodate and tolerate the maintained occlusion at 20 mm above the systolic pressure. • This protocol was associated with improvement in motor learning skills, without change in muscle strength.. • The effectiveness of the above protocol was compared to 200mm of pressure and thenvaried in terms of the number of cycles (e.g. 3 or 4 cylcles instead of 5 cycles and the outcomes were the same [210,213]. • Adverse effects of RLIC are bruising of the skin, complaints of some pain with compression of the cuff and the feasibility of carrying out the protocol in the outpatient physical therapy clinic. • Other researchers have reported RLIC can increase strength [214-216]. • In Japan, the parameters of ischemic conditioning involve compressing to a systolic pressure at 200 mg instead of 20 mm above the systolic pressure [211]. • Specific research studies are needed to evaluate if there are unique effects of RILC on FHD beyond priming the nervous system. **Restricted Blood Flow (RBF)** • The objective of f blood restriction is to specifically increase strength as patients engage in strengthening exercises while proximal limb constriction is provided with a proximal limb strap (BFR). • The purpose of RBF is to restrict venous return while still allowing arterial flow, allowing blood to pool in a working muscle [217]. • In FHD, the problem is motor control rather than weakness. • BFR may not have the same benefit as RLIC in terms of improving motor learning and motor control for patients with movement dysfunction. • Studies specifically comparing the benefits of RLIC and BFR for patients with FHD are needed **Strengthening Inspiration** • Oxygen delivery may be increased by strengthening inspiration. • Based on recent studies at the University of Colorado [218-220] forced inspiration was found to increase general oxygen delivery and decrease fatigue in healthy adults. • The protocol included 30 resisted inspiratory breaths in the morning and 30 resisted breaths in the evening. • It is possible to purchase equipment to make this protocol easy to do at home. (e.g. Power Classic Breathe; www.powerbreathe.com). • Specific studies on the benefits of strengthening inspiration to prime the nervous system to learn versus improving effectiveness of rehabilitation of patients with FHD have not been carried out.
Balance Neural Excitation and Inhibition	**Non-invasive Brain Stimulation** • Non-invasive brain stimulation focuses on improving the balance of neural signals (e.g. decreasing excitation and increasing inhibition) [221-223]. Modalities include repetitive Transmagnetic Stimulation (rTMS), Repetitive Transcranial Direct Current Stimulation (rTCDS) or Functional Ultrasound (FUS). Non-invasive brain stimulation with rTMS or rTCDS apply cathodal stimulation for inhibition or anodal stimulation for excitation. • Functional ultrasound is another approach to balance neural signals [153,157]. • Non-invasive brain stimulation may be paired with brain retraining [222]. • In general, there are minimal risks to rTMS, rTCDS or FUS, but specific guidelines for the timing of the stimulation, the intensity and the duration of stimulation are still under study.. [224-226] and rTCDS [227-230]. • In the US, this intervention is still considered experimental; individuals must participate in a clinical research trial to engage in this therapy.
	Limb Immobilization • Immobilization of the hand has been proposed to reduce the hyper-excitability of the dystonic muscles. • There are several objectives of immobilization.
Atrophy Dystonic Muscles	• First is to atrophy the dystonic muscles • Second is to decrease the excitability of the dystonic muscles [231-234]. • Third, is to use immobilization or non-use to reduce the size of the topography representing the hand and fingers on the sensory and motor cortices [90,235-238] • Studies confirm that immobililization can weaken and atrophy muscles and change topographical maps in those with early onset FHD [90].
Fatigue the Dystonic Muscles	**Perform Repetitive Maximum Muscle contractions of Dystonic Muscles to create Fatigue** • Fatigue can be viewed as a way to temporarily weaken the dystonic muscles to prepare them for retraining [90]. • Individual muscles can be selectively fatigued with repeated, maximally resisted, contractions • The muscles selected should be the overly excited muscles. • During the temporary period of fatigueof the dystonic muscles, the patient may be able to begin neural retraining without abnormal movements.

Studies suggest the neurophysiology of FD is not consistent across all affected inividuals. It is more than a sensorimotor problem, but also includes psychological and cognitive/attentional challenges [239]. FD represents a range of heterogeneous conditions leading to excessive and sustained muscle contractions which lead to abnormal postures and involuntary movements. There is overflow of electromyographic activity to inappropriate muscles, slowness in turning muscles off and increased variability of voluntary movements. Anatomically, there are disturbances in the basal ganglia, altered thalamic control of cortical motor planning and executive function and abnormal regulation of the brain stem, cerebellum and spinal cord inhibitory mechanisms [60] Despite these neurophysiological complexities and impairments, the brain is adaptive and can change [158-161].

Although the principles of reorganizing brain topography are well documented in basic science research, integrating the principles of neuroplasticity into clinical retraining for recovery versus compensation is challenging [162]. The primary objective for neural adaptive brain retraining for FHD is to restore normal anatomical and functional brain topography of the hand as a foundation to recover normal voluntary, task specific motor control [143,158,160-163]. In FHD, compromised sensory and motor area representations/differentiations of the involved dystonic limb have been observed [73]. In patients with FHD, abnormal sensory feedback has also been associated with the abnormal movements [24,64,68]. If there are mild dystonic movements noted in areas other than the hand (e.g.,blepherospasm, postural dystonic movements, segmental dystonia of the limb, cervical torticollis, dysphonia),the clinician should address all of the movement impairments (e.g.,training: http://www. fariastechnique.com/blepharospasm).

A summary of the elements of neural adaptive behavioral reraining based on the principles of neurplasticity are summarized in Table 4 [10,48,55,57,68,143,161,162,240-242,244]. A summary of some specific sensory, sensorimotor and motor retraining techniques are outlined in Table 5 [241-243]. For example, specific sensory, sensorimotor and motor brain retraining paradigms might start with training general sensory and fine motor skills [245-249] without excessive force, (e.g. grip) anxiety or stress. General fine motor tasks such as handling objects, screwing tasks, placing pins in a hole, dealing cards, building models or putting together block puzzles can be included. The sensory training usually starts with peripheral, tactile training, (e.g., determining presence or absence of a stimulus, distinguishing sharp/dull or temperature) progressed to cortical sensory discrimination tasks pertinent to the compromised target specific fine motor task (e.g., graphesthesia, stereognosis, localization, lateralization) [63,90,123,192]. Tasks to improve spatial and temporal integration of somatosensory inputs (e.g.,ordering sizes of objects, completing temporal sequenced activities) might also need to be addressed in individuals with different types of FHD [241,242]. For patients having difficulty with improvement in tactile discrimination, auditory and visual task training could help enhance learning [240].

Table 4: Elements of Adaptive Neural Retraining for FHD [10,48,68,143,161,162,240,241,242,243,244].

Specfic Neural Retraining Activities Should Contain the Following Elements
• Focused attention by participant • Positive expectations by clinician and participant • Observation of others performing target task normally • Mental practice of the target task • Quality, stable biomechanics without abnormal movements or stress • Good posture • Task performance progressed from unusual positions/environments to the usual/typical • Sensory, motor and task specific practiceindividualizd to participant • Activities adapted to participant occupation (e.g., musician, writer, golfer) • Progression iof task difficulty (e.g., complexity, speed) • Feedback provided for information and motivation • Multisensory elements integrated into all functional activities (e.g., tactile, vidual, auditory, proprioceptive) • Supervised practice reinforced with consistent, creative, repetitive self controlled practice • Dual tasking incorporated into targt specific task practice • Adequate dosage (e.g., sufficient repetitions spaced over time) • Creative and interesting with focus on the outcome • Fun, fun, fun

Once improvement is noted in the accuracy of sensory processing, sensory motor retraining should progress to the practice of similar and then target tasks. Performing sub components of the target task or performing tasks similar to the target task (e.g., finger painting in preparation for writing) may be therapeutic. Task specific performance may then proceed to task execution in unusual positions (e.g., supine, inverted or side-lying) or task performance in unusual environments (e.g., high altitude, football field) or in unusual media (e.g., water, shaving cream) [250,251]. Retraining target specific performance could also be initiated by temporarilyusing an alternate, uninvolved body part to perform the target task (e.g., using the toes to feel the target instrument or to hold a pen or a paint brush to practice writing or drawing or using the uninvolved hand) [164,252]. Practice of the target task might be facilitated by using an assistive device to control the involuntary digit movements [253]. Robotic technology can stabilize, assist movement and create a protocol to assure adequate, safe repetitions. [254]. Starting task practice slowly and then increasing speed as in learning a new musical piece has been reported as effective [255].

Neuroplasticity Principles and Sensory, Motor and Sensorimotor Retraining Strategies for FHD

Rehabilitative brain retraining strategies for FHD are extensive. These strategies range from biomechanical retraining to improve musculoskeletal stability [10], slow down exercises to enable performance without dystonic movements [255], comprehensive musical retraining [256], laterality training, mental practice/practice or mirrortherapy (e.g., graded motor imagery) [175,257], simple sensory training [246,248], general fine motor training [249], Learning Based Sensorimotor Training (LBSMT) [250,251,258], forced use-Sensory Motor Tuning (SMT) [253,259-263], neuro-biofeedback [264-266], body awareness training [267], neuromuscular retraining, (https://www.fariastechnique.com/), imagery, peripheral electrical stimulation (Functional Electrical Stimulation-FES); Transcutaneous Nerve Stimulation (TNS) or Somatosensory nerve Stimulation (SES). [268-270], kinesiotaping [271], to dry needling. Most commonly, several rehabilitative neural adaptive strategies are needed.

There are commonalities as well as differences in current sensory, motor and sensorimotor brain activities for FHD. Some strategies are implemented within an intense, supervised, forced use protocol like Sensory Motor Retuning (SMR) (e.g., progressive splinting and forced task practice over a two-week period,6- 8 hours a day) [253,260-262]. Other strategies emphasize general sensory retraining rather than task specific sensory training [245] or general fine motor training rather than task specific motor training [247-249]. Some behavioral strategies use specific sensorimotor training techniques such as Braille reading to restore writing skills (supervised and home practice) [246]. Other approaches combine a variety of activities.

The comprehensive approaches include sensory discrimination training to improve accuracy, biomechanical coaching to improve safe performance techniques and biofeedback to provide information on accuracy of performance, learn to turn off undesirable muscle contraction and turn on desired muscle contractions or change force. In addition, comprehensive programs may also include mental practice, graded imagery, attended, progressive cognitive training (e.g., to improve attention and preparation for movement) as well as progressive task specific practice (Learning Based Sensory Motor Training-LBSMT) [88,90,123,194,264]. See Table 5, The different approaches may need to be carried out for months or years [256]. Some priming strategies like non-invasive brain training (rTMS and rDCS) may be integrated to decrease excitation or increase inhibition supplementing adaptive neural retraining [225,226]. For patients with FHD who also have upper limb and neck involvement, dry needling has been integrated as a priming strategy. (https://www.youtube.com/watch?y=Non1KSId0bI). Most of the rehabilitative strategies begin with intensive supervised training for several weeks or months complemented with a home program. Usually patients decrease supervised visits to weekly or monthly with limited work responsibilities up to a year or more. Home practice is critical.

Effectiveness of Intervention Strategies for FHD

Medical management

The focus of this manuscript is on neural behavioral retraining for FHD. However, the foundation of treatment begins with quality medical management. At this time, injections of botulinum toxin are the standard, type Ia evidence-based medical treatment to reduce dystonic muscle cramping in FHD [141,146,281]. Drug induced weakness with botulinum toxin is usually temporary, lasting about 3 months. Most patients then require additional injections. Patients may become dependent on repeated injections. There has been some evidence suggesting botulinum toxin injections over time may actually improve cortical firing patterns, particularly if the injections are paired with retraining [282].

Table 5: Example of a Multi-Sensory, Sensorimotor and Motor Retraining Activities.

I. Multi-Sensory Discrimination Training: visualization, verbalization, auditory discrimination, graded tactile stimuli, tactile discrimination, mirror imagery training

A. Tactile/Stereognosis/ Graphesthesia/ Graded Tactile Discrimination
- Sort objects with different sandpaper quality on the sides by shape, weight or roughness
- Without looking, reproduce size and geographic location of numbers, letters and designs drawn on the skin
- Texture dowels with different fabrics: Match the texture of the fabric on the table with the texture attached to the wood parts behind the curtain.
- Create multiple textured pegboard and pegs with that texture at one end; match pegs behind the curtain with the pegboard based on the texture and place in the hole
- With hands behind a curtain, have matching beans hidden inside therapeutic putty; find the beans in the putty, remove them and match them. (e.g. black beans, kidney beans, white beans)
- Put coins and paperclips in a box of mixed beans and while blindfolded, search for matched pairs of the coins and paper clips
- Put different pairs of keys on a chain; while blindfolded, try to match the keys.
- Clay modeling: Create shapes with clay. Place the shapes behind a screen with extra clay. Find one of the shapes behind the curtain and then make the same shape with the free clay.
- Stereognosis: Place small pairs of objects behind the curtain, discover the objects and match them through touch and manipulation.
- With a blindfold on, place dominoes on a table. Place other dominoes in a bag. Try to matchthe dominoes on a table with hidden dominoes in a bag.
- Play dominoes with a friend both blindfolded.
- Place match pairs of magnetic letters/wooden alphabet blocks/geometric puzzle pieces/ put together puzzles without looking play/Perfection game with pieces behind a screen. Find and pull pieces out of the bag and place them in their proper places on the boards.
- Scrabble: Find a partner. Both wear blindfolds after delivering letters to each. Without vision (except to begin one's turn), feel and manipulate letters to spell words (partner must feel letters to confirm the word).
- Velcro different buttons on material Place this set up behind screen. Place the matching buttons in front of the screen. Feel the button behind the screen and then try to match the button from the front to the button behind the screen.

B. Temperature
- Separate plastic cubes based on different temperatures.
- Place hands and fingers in different immersion temperature containers; differentiate the temperature based on warm, cold, and medium.
- Select hot packs/cold packs based on different temperatures.

C. Weight (barognosis)
- Sort blocks of different weights
- Sort weighted eggs or balloons (1,2 or 3 oz)
- Make a list of different weights (in random order). Then look at the list and a) put whole hand on a food scale at the given weight and then b) learn to apply specific pressures with each finger to the specified weight

D. Auditory Localization/Discrimination
- Put on a blindfold. Have a friend stand behind you or in front of you and make a sound in different locations. The trainee needs to point where the sound was delivered.
- Put on a blindfold. Have a friend with two sound makers. Have the friend deliver each sound well separated and then deliver the sound closer and closer together. The trainee has to decide if there was one or two. Start with the same sound making and then have two different sounds.
- Have different sounds presented and trainee must determine if the sounds are the same or different.

E. Visualization
- Have a friend stand behind you to help present pictures in different fields of vision. Have one or no image presented and the trainee has to say if there was a image or not (versus nothing on the presentation sheet)
- Have a friend stand behind you with two cards. In different fields, have the friend present either one blank card and one with something on it, two blank cards or two object cards. The trainee has to determine what was on the card.
- Have a friend stand behind you and present a card quickly in different fields. The trainee must say what is on the card
- Have a friend stand behind you with a pen. Then have the friend start in different fields and bring the pen closer and closer until you can see it.
- Get a workbook that includes objects buried into different backgrounds and you have to circle the objects
- Get a book with a word buried multiple times into a puzzle . The trainee must circle the words (parallel, longitudinal, oblique)
- Find a program on line that presents different visual images and you have to find those that are the same (e.g. Brain HQ at Positscience.com; Lumocity)

F. Lateralization
- Purchase lateralization cards from Noi.com
- Recognize Hands (maybe even Recognize Shoulder as well)
- Follow instructions to train lateralization

G. Vocalization
- Find a program on line that presents different vocalizations at different amplitudes and you need to indicate if you hear them
- On Brain HQ there is a voice amplitude training component where you have to simulate the vocalization you hear

H. Mirror Imagery
- Remove all jewelry for both hands. Use a mirror and place the unaffected hand in front of the mirror and the affected hand behind the mirror (noi.com has a mirror or can get a picture stand and put a mirror on each side)
- It is possible to do many activities here
- Place the same objects appropriately on both sides of the mirror and then feel the different objects (e.g. feel same object in both hands)
- Have someone touch you on the same place on each hand. Have the friend touch with different objects with different characteristics. Make the contact feel the same on both the affected and unaffected hands
- Hold a pen in each hand
- Feel the pen
- Hold the pen lightly
- Practice picking the pen up and putting it down
- Practice making simple printed letters and then cursive letters
- Practice drawing a design
- Practice writing a word
- Graded motor imagery
- Get a book on graded motor imagery (e.g.Noi.com; Moseley , Graded Motor Imagery)
- Folllow guidelines in book

J. Visualization
- Have a friend stand behind you to help with presenting different objects to you in different fields either on the right or the left (you have to name the object)
- Have a friend stand behind you and present different objects bilaterally and you have to determine if the same or different

II. Sensory motor training
- Practice reading Braille as therapy
- Put sets of buttons and button holes out on a table. Blindfolded, try to button the buttons. Time yourself.

- Nuts and bolts: Place a plate of bolts and screws of different sizes behind the curtain or put the bolts and screws in a bowl and wear a blindfold. Try to put the correct screws and bolts together
- Stone/bean/coin sorting: Place items of different sizes on a table. Place similar items in a bag. With a blindfold on, retrieve items of different sizes from a bag and match the ones on the table. (Time yourself and try to get faster)
- Bottle caps: Find bottles of different sizes with different cap sizes. Remove the caps and place behind a screen. Place bottle caps in front of the screen and take the caps and try to put them on the right bottle behind the curtain.
- LEGO rebuilding: After you or a friend creates some shapes with LEGO blocks, place the shapes behind the curtain. Reach behind the screen and manipulate one of the shapes and then make a similar shape in front of the curtain.
- Do finger painting in shaving cream or be artistic with real finger paints on paper
- Place puzzle pieces behind a screen. Then reach behind the screen and assemble the puzzle. (Could do the same thing with a blindfold on)
- Use Mirror Therapy focusing on movements
- Practice Mirror Therapy focusing on movements
- Practice folding a towel
- Practice stacking objects
- Practice sequential finger movements
- Have someone else place their hand in front of the mirror and you keep your hand behind the mirror. Then have the helper make movements while the trainee accurately copies the movements (progressing from simple to more complex, slow to fast)

III. Attentive, Sensory-Motor- Cognitive Training

- Brain HQ, Postiscience.com
- Lumocity. Com
- Variousnewinfor.com
- Do Suduko
- Get a Calendar that has daily brain games
- Download brain games from www.happy-neuron.com
- Do crossword puzzles
- Play strategy games with others
- Play word /phrase games
- Play Bridge
- Play Chess
- Do puzzles
- Read the news daily and discuss
- Can try to participate in supervised, sensory motor and cognitive training programs ina rehabilitation institution
- BrainPort Artificial Vision Device: improves driving skills and touch as vision substitution
- vOICe [272] trains visual to auditory
- Guide Cane:funnels tactile information from walking stick to the brain
- Auditory training: Discriminate two sounds close in time improves touch
- Visual training for double vision:Computer Orthoptics: Computerized Home Vergence Exercises
- Interactive driver training [273].
- Can play home computer, sensory motor and fine motor games [274].
- Brain Metrix Website [275].
- Online Kenken game [276].
- Queendom Website [277].
- Eidetic Memory App [278].
- MyBrainTrainer website [279].

IV. Intensity and Frequency of Behavioral Sensorimotor Training

- One hour of training 2-3x/week for 6-8 weeks or 5x/week for 1-2 weeks followed with 5-7 weeks of home practice. General sensory activities daily for 2 weeks [88].
- Braille reading daily 30-60 minutes/day up to a year [245].
- 2.5 hours/visit. 2x/week for 5 weeks [280].

While weakening the most dystonic muscles with botulinum toxin injections may enable some patients to continue to use the hand at the target task (e.g., typing or writing), the injections often fail to enable musicians to achieve sufficient, normal, voluntary, task specific fine motor control of movements to return to quality performance [144,152].

Interestingly, adverse events following botulinum toxin injections are not well understood. Physicians are not required to report adverse effects from botulinum toxin injections to the FDA. There are reported cases where excessive muscle weakness has developed post botulinum toxin injections. For some patients, the toxin injections may lose effectiveness over time. In a multicenter descriptive follow up study of 2649 musicians [283], 240 musicians were diagnosed with Musician's Dystonia of the Hand (MFHD). Of those with MFHD, 24% received botulinum toxin injections. Thirty percent reported substantial improvement, however, most of the individuals. ultimately discontinued this therapy due to minimal benefits.

Medications for anxiety may reduce some performance challenges triggered by stress and anxiety, especially for musicians. However, these medications may not directly remediate the involuntary dystonic movements. Patients often inquire about marijuana to manage FHD. Currently the effectiveness and safety of marijuana for FHD is still under review [284].

Deep brain stimulation (Thalamic and Pallidal) as well as thalamotomies are not commonly recommended for patients with FHD in the United States, but such treatment has been associated with good results in Japan and Europe [285-287]. A retrospective descriptive study of 171 patients following a ventro-oral thalamotomy was reported by Horisawa from Japan [157]. The mean age at the time of surgery was 37.1 years (±12.3 years). The mean age at disease onset was 29.1 (±11.7 years) with the mean disease symptom duration of 8.0 (±8.2 years). The mean task specific dystonia scale (range of 0-5) was 1.72 (±0.57) at baseline (n=171). At follow up, (one week, 3 months, 6 months and 1 year) the TSDS mean score was significantly higher than baseline: 4.33 (±0.85) [N=171]; 4.30 (±1.06) [N= 162]; 4.30 (±1.13) [N=106] respectively. The 72 patients who were last contacted had a TSDS score of 4.39 (±1.07).

In this descriptive outcome study, adverse events developed in only 6 patients (3.5%) and ranged from dysarthria (n=2), hand dysthesia (n=1), verbal recall disturbance (n=1) to mild foot weakness that did not compromise daily activities (n=2). Temporary adverse events developed in 28 patients (16.4%): Dysarthria (N=10), verbal recall disturbance (N=8), hemi-body weakness (N=6), weakness of the foot (N=3) and facial palsy (N=2). Two patients had an infection of the surgical site and 2 patients had a chronic subdural hemorrhage. In this study, progression to the contralateral hand (bilateral hand symptoms) was observed in 25 patients (24.2%). Eighty percent of the patients were classified as good responders (138), 30 patients as partial responders (17.5%) and 4 as non-responders (2.3%). Eighteen patients (10.5%) experienced symptom recurrence after the ventral-oral thalamotomy.

In one case in India, the news media reported on a guitarist who was taken to the operating room for focused ultrasound. After this targeted stimulation, the surgical incision was closed and the musician could play normally [53,288]. Asahi et al., [287] reported positive functional outcomes post focused ultrasound in two cases of patients with writer's cramp.

In case reports and descriptive studies, surgical release of tight retinaculum or peripheral nerve adhesions (e.g., ulnar nerve transfer) paired with strengthening, stabilization and flexibility exercises have been associated with positive outcomes [10,57,72]. In a recent follow up descriptive study reported by Keller [283,289], a greater proportion of musicians with FHD had signs of ulnar neuropathy compared to healthy musicians (30% versus 22%). Twenty seven of the 66 musicians with dystonia and ulnar neuropathy had ulnar entrapment release surgery with most patients reporting improvement in ulnar signs but minimal improvement in dystonic movements.

Neural behavioral retraining

Once the nervous system has been primed to learn, neural behavioral, sensorimotor retraining is started. A summary of the research evidence on the effectiveness of strategies for sensory motor intervention strategies for patients with FHD is included in Table 6. There are many confounding variables that can interfere with the effectiveness of behavioral, sensorimotor training which range from genetics to environmental conditions to psychosocial factors to research methodology. The lack of large randomized clinical trials is a significant limitation in interpreting effectiveness of interventions.

See (Table 7) [354] The individuals with FHD who may be most likely to return to normal performance of the target task are those who comply with medical recommendations, have good family support, can take a break from work and have positive expectations to recover. In addition, those who successfully rehabilitate are those who can minimize work requirements, mentally rehearse the target tasks, recover the memory of performing the target task normally, maximize a healthy life style, manage stress, improve the biomechanics of performing target specific tasks, and perform intensive, variable, creative schedules of high quality, progressive sensorimotor behavioral retraining.

Table 6: Summary of Effectiveness of Different Neural Priming and Sensorimotor Behavioral Training Strategies for FHD.

Type of Strategy	Specific Intervention	Summary of Research Studies
Prime the Nervous System to Lear	**Non-Invasive Brain Stimulation**	• Non-invasive brain stimulation (rTMS and rTCDS) may set the stage for improved brain retraining for patients with FHD by imrproving the balance of excitation and inhibition in different parts of the brain [290]. • Non-invasive brain stimulation strategies need to be repetitive, but the time, the number of repetitions and the target of the stimulation are not clear. • It is also not clear, if the stimulation should be bilateral and if simultaneous sensorimotor behavioral training is needed [226,291]. • In Europe and Canada, patients may receive non-invasive brain stimulation as part of their medical care for FHD. • In the US, non-invasive brain treatments are still considered experimental requiring individuals to enroll in a clinical trial to try non-invasive brain stimulation. • The effectiveness of non-invasive brain stimulation varies • Type of stimulation;rTMS [69,224-230,292-309]. There is good research evidence supporting the effectiveness of non-invasive brain stimulation within the context of neurorehabilitation for patients with a broad range of neurological problems ranging from to stroke, pediatric brain injuries, TBI, neuropathic pain, spinal cord injuries and FHD [222,223]. • Non invasive brain stimulation is generally safe, with minimal but mild adverse effects (e.g. headaches, seizures). • Some clinicians recommend the adjective "non-invasive" should be removed with these techniques referred to as brain stimulation (conservative or rehabilitative) [310]. • Cho and Hallet carried out a systematic review of the effectiveness of rTMS and rTDCS for FHD. (fourteen studies were included in the review,7 studies of rTMS and 7 studies of t DCS). • Various research designs were utilized with the cross over design the most common. • Most studies included a small number of subjects. • There were no large randomized clinical trials. • The reviewers reported low frequency stimulation (<1Hz) was associated with decreased cortical excitability and high frequency stimulation (>5Hz) was associated with increased cortical excitability. There were no serious adverse effects. • The brain areas targeted for stimulation included: M1 (Primary Motor Cortex); PMC (Pre-motor cortex); and S1 (Primary Sensory Cortex). • The stimulation was either on the contralateral side to the dystonic hand or simultaneous stimulation was provided bilaterally. • Tvwaert et al., reported improvement in motor control in patients with writer's cramp after subthreshold low frequency rTMS over the pre-motor cortex, with simultaneous sensorimotor integration training. • Siebner et al., [292] reported inhibitory rTMS on M1 had positive benefits on dystonia. • Murase et al., [224] reported the PMC was a better target than the M1 or the Supplementary Motor Area (SMA) for rTMS. • With the PMC as a target, three studies reported positive results using physiologic or behavioral outcome measures [225,296,300]. • Some individuals were classified as responders and others non-responders. Individuals with impaired inhibition prior to noninvasive brain stimulation responding most favorable [225]. • For rTDCS, the target of the stimulation and the number of stimulation sessions was varied [69,227,228,293]. • Anodal transcranial direct current stimulation was reported to have a positive effect on motor sequential learning in healthy subjects [307]. • Cathodal stimulation did not improve motor control in musicians [304,305]. In studies for patients with writer's cramp, rTCDS stimulating the cerebellum (10 weeks, 10-20 minutes/session) was not associated with improved cortical plasticity [69,227,228,293]. • For rTDCS, the target of the stimulation and the number of stimulation sessions was varied [69,227,228,293]. • Anodal transcranial direct current stimulation was reported to have a positive effect on motor sequential learning in healthy subjects [307].

		• Cathodal stimulation did not improve motor control in musicians [304,305]. In studies for patients with writer's cramp, rTCDS stimulating the cerebellum (10 weeks, 10-20 minutes/session) was not associated with improved cortical plasticity [69,227,228,293]. • Furuya et al., [228] reported improvement (up to 4 days post stimulation) in rhythmic accuracy of sequential finger movements of the affected hand after simultaneous cathodal stimulation over the affected cortex and anodal stimulation over the unaffected cortex, paired with concurrent motor training. • Fan et al., [308] reported significant improvement in speed-accuracy after 5 days (20 minutes per session) of anodal tDCS over MI in healthy subjects. • Marceglia et al., [309] reported significant broad ranged improvement in motor skills, pain, and tremor in two musicians who received cathodal stimulation over the pre-motor cortex with simultaneous anodal stimulation over the uninvolved pre motor cortex. • Cho and Hallet [223] concluded • Both rTMS and rTCDS appear to have positive effects. • rTMS and rTCDSetreatmentsmay need to be paired with sensorimotor retraining strategies to maximize effectiveness. Cho and Hallet 223. • Cho and Hallet concluded further studies were necessary to confirm the treatment sites, type of stimulation, dose, frequency and duration of stimulation. • There are no controlled research studies comparing the effect of life style modification on improving motor control for patients with FHD. • Life styles which include good nutrition, adequate exercise, quality sleep and good stress management contribute to positive health, well-being and aging. [311,312]. • The importance of life style and positive health have been extensively studied by many researchers and is strongly supported in terms of current health policies. (US Department of Health and Human Services. Centers for Disease Control and Prevention) • The most common measures of outcome effectiveness related to life style • Increased length of life. • Improvement in immunity from disease and increased the potential for healthy cells and neural learning across the life span [177]. • From a cellular perspective, [177,311]. • The length of the telomeres at the tip of the chromosonecan be an accurate estimate of aging [177,311]. • Cell mitosis also represents a state of aging.
	Life Style Management	• When our cells stop dividing, they reach a stage of senescence. • During senescence, cells leak proinflammatory substances which increases vulnerability to pain, chronic illness and cognitive degeneration [313-316]. • Individuals undergoing neural rehabilitation can benefit by creating a foundation of a healthy life style.
	Increase Oxygen Delivery	**Hydration, Strengthening Inspiration, Remote Ischemic Limb Conditioning (RLIC), Restricted Blood Flow (RBF)** • There are no specific, targeted, randomized clinical research studies evaluating the effect of oxygen enhancement to improve readiness for neural learning or brain retraining for patients with FHD. • Adequate levels of oxygen are important to facilitate healing and to maintain healthy cells [317]. • Measuring blood pressure, oxygen levels and temperature are standard monitoring parameters for health management. • For otherwise healthy adults, research supports the benefits of: • Strengthening inspirationn [318] and RLIC to increase the systemic delivery of oxygen. • RLIC is associated with improvement in motor learning [210,212,213]. • RBF may increase muscle hypertrophy under conditions of proximal occlusion of blood flow • In conclusion, for individuals engaging in brain retraining, it is importantto maintain high, therapeutic levels of O^2.
	Immobilization	**Immobilization of the Affected Limb** • The objective of immobilization is to create peripheral atrophy of targeted muscles and reduce the central topographical representation of the muscles [237]. There are no large, randomized clinical studies on the effectiveness of this technique, to improve motor learning and motor control • In small pre-post-test design research studies,cast-immobilization was associated with a reduction in dystonic movements in patients newly diagnosed with FHD [235-238]. • For individuals with established FHD, cast-immobilization exacerbated muscle cramping in some of the participants. A randomized clinical trial was initiated in the United States for patients with chronic FHD. This trial was stopped early because the casting increased the dystonia in some participants. (Personal communication). • Immobilization prior to Fine Motor Training • The effect of immobilization followed by general fine motor retraining for patients with writer's cramp was studied by Zeuner et al., [247]. • The hand was immobilized two weeks prior to beginning motor retraining. • The purpose of the immobilization was to minimize the severity of the dystonia and prime the nervous system for learning. • After immobilization, patients performed general, not task specific, fine motor training exercises (e.g. strengthening and flexibility exercises) followed with fine motor training using Braille and writing practice. • Dr. Zeuner reported a significant decrease in the severity of the dystonia and improved voluntary control. • It is difficult to interpret what improvement resulted from the immobilization and what improvement occurred as a result of the motor retraining.
	Fatigue Training	• Fatiguing dystonic muscles may temporarily relieve the dystonic cramping and prime the nervous system for retraining. • There are no large, randomized clinical trials to confirm fatigue therapy alone is sufficient to restore normal motor control in patients with FHD. • However, fatiguing a dystonic muscle could be a useful strategy to prime the nervous system before retraining begins [235].
Retrain the Brain	**General Sensorimotor Training**	• There is substantial research indicating intense, repetitive, stereotypical, sensorimotor movements can degrade the representation of the hand [63,73,80,81,85-87,123]. • There is also evidence attended, repetitive, progressive sensorimotor training spaced over time can improve sensory processing, restore topographical representations and enhance voluntary motor control of the upper limb in patients with a variety of neurological impairments [123,319-326]. • Learning based brain training paradigms can improve cognition and memory as well as slow down the aging process [161]. • The most common sensorimotor training strategies applied to improve task specific performance for patients with FHD include kinematic-ergonomic training, changing hands, slow down exercises, body awareness-neuromuscular training, dancing, general fine motor practice, general sensory training, Braille reading, sensorimotor retraining strategies based on plasticity principles (Forced Use-Sensory Motor Retuning [SMR, Learning Based Sensorimotor Retraining [LBSMR]),imagery (e.g.general imagery,mirror imagery and graded motor imagery), comprehensive programs integrating multiple strategies and the integration of modalities such as transcutaneous electricalnerve stimulation (TENS),neurobiofeedback, and kinesiotaping. • The comprehensive intervention approaches may require as little as months or as long as years of training before significant improvement is noted in target specific performance [41,144,256,327]. • While there are no large, randomized clinical trials confirming the effectiveness of different sensorimotor-brainre-training techniques specifically for patients with FHD, there are small confirmatory clinical trials with no reported adverse effects.

	Kinematic/ Ergonomic/ Biomechanical Training	• Changing ergonomics and biomechanics is emphasized as a potential strategy for preventing as well as treating FHD, particularly for patients with musician's dystonia [10,57]. • Unfortunately, no controlled, randomized research studies could be found to confirm the effectiveness of this approach. • Case series and small controlled studies report improvement in cortical topography as well as movement kinematics in patients with musician's dystonia following ergonomic-biomechanical retraning [23,26,41,152,328]. • The researchers report musician not only need to improve the biomechanics of performance, but each musician must also address life style issues, reduce stress, manage performance anxiety, retrain sensory processing and progressively practice quality, voluntary motor control at the target task.
	Changing Hands	• Following a small study,Woldendorp and Gills [252] reported on the effectiveness of helping patients recover motor control of the affected limb after teaching them to use the unaffected hand to perform the target task. • To enable adequate musical performance, this approach may require adaptation of the instrument (e.g. changing the strings, using a stand or a sling to support the instrument, reconstructing the instrument, using an ergonomic instrument or using a toggle key system to depress a key). • In some cases, it is also necessary to change the composition of the music to accommodate performance with one hand. • To be successful and avoid developing FHD of the unaffected hand, it is important for the individual to remember to address the underlying, aggravating neurophysiological, psychological and personality factors initially associated with development of the dystonia. • There are no large randomized trials studying the long-term effectiveness of this strategy in terms of ultimately recovering motor control of the dystonic hand. After a time, most individuals try to return to performing the task with the affected hand.
	Slow Down Exercises	• Sakai [104] reported on the effectiveness of restoring motor control of the affected hand of musicians with FHD by following "slow down exercises". • No large randomized controlled research trials employing this method alone or in combination with other strategies could be located. • However, historically, musicians use this strategy to practice new, complex repertoires. • The musician begins performance slowly and then methodically increases the tempo. • For patients with FHD, this "slow down" technique may be integrated into coaching within a more comprehensive strategy [41].
	Body Awareness-Neuromuscular Training	• Body awareness training has been a core part of several different intervention strategies [267,327]. • Waissmann et al., [267] reported the effectiveness of body awareness training within a small, pre-post-test design study. • 12 patients with writer's cramp were included (mean age 41.8 years, dystonia for an average of 10.9 years, mostly right handed, without botulinum toxin or physical therapy for 6 months). • The primary outcome measures included the Burke-Fahn Marsden Scale (BFM), the Jedynak Protocol, the Visual Analog Pain Scale and a video recording of writing. • The subjects participated in supervised training 2x/week, 60 minutes per session for 8 weeks. • The patients were also instructed to practice 30 minutes a day at home and focus on minimizing the tension in the hand and upper limb. • During the first 4 weeks, the intervention focused on education, posture exercises, relaxation techniques, flexibility exercises, scapular stabilization and fine motor exercises of the elbow, wrist and fingers. • During the second 4 weeks, with the wrist and fingers immobilized with splinting, the subjects practiced specific writing tasks (e.g. used lined paper, tried to reduce the friction on the pen, made circles, followed dotted drawings, wrote words, letters and numbers, copied headlines from newspapers and then practiced writing continuously for 2 minutes). • Significant improvement was measured in the Burke Fahn Marsden Dystonia Scale and the Jedynak Evaluation. • In addition, a significant reduction in pain was achieved in the wrist, forearm, arm and fingers, but not in the thenar, hypothenar or shoulder regions [267]. • Hand writing quality improved at slow speeds but continued to develop dystonic movements when writing with stress and fast writing. Eight of the 12 subjects rated their self-improvement at 60%. • The gains were similar to those reported by Champagne et al., [256] and Tubiana et al., [329] following their comprehensive re-education program including body awareness training for musicians with FHD. • Bleton [330,331] also described successful rehabilitation of patients with writer's cramp by combining body awareness training with sensory motor re-training to improve postural alignment while writing or performing activities of daily living). • When the patients wrote slowly with close attention to postural alignment, there was significant improvement in writing. • Unfortunately, it was easy for the patients to be distracted and slip back into poor posture. • When posture was compromised, writing became more dystonic. • Unfortunately, large randomized controlled trials are not available to confirm findings. • Farias [332] suggests the foundation for retraining patients with focal dystonia includes attention to body awareness and integration of neuromuscular retraining. • Farias has specifically defined his neuromuscular retraining techniques in a textbook and a website for patients with different types of focal dystpnonia [332]. • The text is also designed to help clinicians manage patients with FD
	Dance	• Dance has been viewed as a type of neuromuscular retraining technique for patients with neurological injuries [333]. • Some individuals with focal dystonia self-describe improvement in their dystonia following retraining with aggressive dance techniques. (https://www.youtube.com/watch?v=DwkHK3rfKO0) • Others self -describe positive outcomes after integrating home programs based on NIA. (https://www.youtube.com/watch?v=tDbgE-S0txY) • Randomized clinical trials support the benefit of dance maintaining mobility and improving balance for patients with PD [334,335]. • Specific randomized clinical trials (RCTs) on the effectiveness of dance to help patients with FHD recover task specific motor control could not be found.
	General Sensory and Fine Motor Training	• General sensory and fine motor retraining programs (not task specific sensory and motor retraining) have been paired with intrinsic muscle strengthening for patients with writer's cramp [247-249]. • In these studies, the sensory and motor programs were similar to those applied to retrain patients post peripheral nerve injury. • The researchers reported improvement in writing with sensory training (quality and speed), but the training did not completely resolve the dystonia [247-249]. • Generalfine motor training was associated with significant improvement in voluntary motor control at the target specific task, but was not completely resolved [247, 249]. • Schafer etl al., [336] added dual tasking to the general sensory and motor retraining; the transfer of training increased to the desired target task. • The evidence for this strategy has not been confirmed with large, randomized clinical trials.
	Braille Reading	• Braille has been used as a sensorimotor retraining strategy for patients with FHD • Reading Braille is a challenging sensory task for those who can "see". • Braille is learned by doing specific lessons, reading books, feeling the braille letters on the elevator and playing games with braille cards, dominoes or checkers. Braille letters could also be placed on a piano or a computer keyboard.

		• In studies conducted by Zeuner et al., [245], individuals with writer's cramp were asked to read Braille daily. • Some reduction in the dystonia with writing was measured after 3 to 6 months of braille training. • The individuals who made the greatest improvement in hand writing were the individuals who elected to continue braille practice for a year [246]. • Even after a year, under stress or when asked to write something quickly, these individuals still reported difficulty with writing. • The braille strategy is promising based on small controlled trials but, no large randomized controlled trials have been carried out.
	Forced Use	• There are several randomized clinical trials supporting the effectiveness of general forced use sensory motor training strategies for patients with neurological problems (e.g. stroke, musicians dystonia) [257,263]. • For patients with muscians dystonia, the forced used paradigm is referred to as Sensory Motor Retuning (SMT) and it includes intense daily training for two weeks. • This strategy integrates forced use with orthotic control of the dystonic fingers applied during musical task practice [253,260-262]. • Studies confirming the effectiveness of SMT are limited to case series, case reports and small clinical pre-post-test design studies [253,260-262]. • Following intense SMT improvement in performance and cortical reorganization has been reported • There were greater gains in guitarists than pianist. • In a case series (N=8), Berque et al., [337] carried out a clinical trial applying constraint-induced therapy and specific motor control retraining. • After12 months of training, the researchers reported musicians with FHD significantly decreased the number of abnormal movements demonstrated per second during instrumental play (Frequency of Abnormal Movements Scale FAM).
	Behavioral Sensory-Motor Retraining for Musicians with Dystonia	• For musicians with FHD, a recent doctoral meta-analysis was carried out by John Kretchmer [338]. • This meta-analysis included 8 small randomized trials and case studies including different behavioral sensory motor retraining strategies for musicians with hand dystonia. • The analysis focused on the documentation of functional outcomes. • In these studies, patients self-rated significant improvement in motor control (<0.05; effect size 3.20 [1.94-4.46]). • The clinicians coordinating the care for the musicians rated significant improvement in motor control. (p<0.05; grand effect size of 2.90 [1.68- 4.13]. • In six studies which included an objective measure of motor performance, there were no significant gains in objective measures of motor control. (p>0.05; effect size of 0.45 [-.09-1]). • This suggests patients subjectively felt better and clinicians assessed improvement, but objective, confirmation of improved motor control could not be documented. • In a musician's clinic, a retrospective, descriptive study of musicians-pianists was carried without auspicious who had received care over the last 4 years. • Seventy-three musicians were contacted. • Fifty-four completed a non-standard questionnaire regarding therapy received as well as a 2 minute analysis of playing two-octave C-major scales on a MIDI piano (objective analyses of performance). • Only those completing both the initial and follow up piano kinematic examinations could be included in the analysis of results. • Of the respondents, 98% reported problems of dystonia with other activities besides musical performance. • Half of the patients were taking medications (53% botulinum toxin and 51% trihexyphenidyl). • Most individuals reported participating in multiple therapies including: retraining (87%), hand therapy (42%,) relaxation techniques (38%), physiotherapy (30 %), psychotherapy (23%) , acupuncture (21%) and body techniques (21%). • 85% of the subjects reported improvements in motor performance, but objective gains in task specific motor performance were only documented in 42.9% (with deterioration in 4.8%). • Retraining therapy, relaxation techniques and change in teacher explained 52% of the variance [139]. • While these findings support the benefits of retraining, relaxation and music instruction by a coach, were descriptive studies, not controlled, randomized intervention study. • A multi-center descriptive review of data was reported by Keller [283]. • This review included 2649 performing artists from several different health clinics treating performing artists. • There were 240 cases (9%) of Musician's Dystonia (MFHD) and 532 cases of musicians with ulnar nerve entrapment (but no dystonia) (20%). • 10% with MFHD had a family history of movement disorders. • Brass and percussion players had less MFHD than piano players or those who plucked strings. • 75% of those with MFHD had a pure flexion dystonia, most involving the flexion of the ring and little fingers. • 75% of those with MFHD reported an associated event prior to developing the dystonia (e.g. increased practice, new technique or a new instrument) or a non-musical event (e.g concurrent neuropathy, overuse injury or emotional stress or trauma). • About 50% of the musicians had continued to play over the years, but felt they were impaired. • This descriptive study was presented at the International Congress of Parkinson's Disease and Movement Disorders on September 24, 2019. • Theconclusion was that better musical training was needed to avoid focal dystonia in musicians.
	Specific Instrumental Training	• Based on historical descriptions of musical retraining, specific piano training techniques can induce neural adaptation to improve performance in patients with musician's cramps [256,329]. • Jabusch et al., [152] reported on a long-term outcome study of 144 musicians with dystonia. • The musicians self-reported positive outcomes post treatment. • Unfortunately, the positive subjective reported gains were not documented with objective kinematic measurements. • This was a descriptive follow up study. • Some artists have developed instrumental instructional programs for teachers and artists (e.g. David Leisner, guitar [163], Dorothy Taubman, piano) • http://www.youtube.com/watch?feature=fvwp&v=66V8AECWOTc&NR=1 • http://www.youtube.com/watch?v=Xkc4Uz387kc • http://www.youtube.com/watch?v=IFOeaGKL_5c • No large randomized controlled intervention studies using instrumental training alone could be located.
	Imagery	• Imagined hand movements activate primary motor and sensory cortical areas as well as cerebellar motor areas [165,167,175,257,339-343]. • Small, but controlled randomized trials using graded motor imagery, provide evidence imagery can significantly reduce the severity of pathologic limb pain [174,175] . • Mirror imagery (using a mirror reflexion on the unaffected hand) that as been effective in relieving phantom limb pain [167]. • Graded motor imagery (mental imagery combined with mirror imagery to move a limb) has been correlated with improvement of upper limb function in patients post stroke [172], particularly when integrated into retraining programs for the hand [344]. • However, no randomized clinical trials could be located to confirm the isolated benefits of mental imagery, mirror imagery or graded motor imagery for restoring voluntary hand control in patients with FHD. • Lateralization training (wwwnoigroup.com Recognize: Hand), mental imagery and mirror imagery [171] have been integrated into LBSMT. • It is difficult to determine which components of LBSMT (such as imagery) contribute the most to effectiveness of retraining. • One small graded motor imagery study was recently carried out with musicians with FHD.

		• The purpose of the study was to evaluate the effectiveness of a home-based program (1 session/day for 4 weeks) including graded motor imagery training. • Left/right discrimination (lateralization training), explicit motor imagery and mirror therapy were combined into a novel, home based graded motor imagery training paradigm (http://www.gradedmotorimagery.com/). • Six patients with mild to moderate musician's dystonia participated. • The findings from this pilot study were promising. • Improvement was documented as a decrease in severity of the dystonia and improved ability to play simple musical pieces. • Unfortunately, no decrease in the Dystonia Disability Scale was measured. • The authors suggested further study should be pursued [345].
	Modalities Modalities (TENS, Biofeedback, Kinesiotaping)	**TENS** • Several small TENS research studies have been carried out with patients with FHD [268-270]. • Initially, TENS intervention provided some improvement in motor control, but the effects were not long lasting. • If pain is an element in a patient with FHD, then TENS could be helpful tomanage pain. • There are no large randomized trials studying the effect of transcutaneous electrical nerve stimulation (TENS) to modify the involuntary movements for patients with FHD. **Biofeedback Training** • Biofeedback training has most commonly been integrated into programs for patients with writer's cramp [346-351]. • Most of the studies were small, pre-post-experimental studies. • No large randomized trials were located. • In most studies, the feedback included a computerized feedback device applied to a writing pen. • The total duration of quality writing, grip force and pressure down, in addition to vertical writing frequency were considered the most important outcomes to measure [346]. • The outcomes improved significantly post training [346-351]. **Non-invasive brain stimulationput** • In 2013, Atashzar studied the benefits of adding **non-invasive brain stimulation** or TENS to the biofeedback program. • The patients receiving non-invasive brain stimulation had greater improvement in cortical reorganization, somatosensory function and writing [266]. • In 2016, Atashzar and colleagues included botulinum toxin in addition to biofeedback training. • While all subjects improved post training, those who received botulinum toxin in addition to biofeedback, made greater gains in writing [266]. • The effect of a modified pen grip paired with subtree modified pen grip progressive writing (e.g. slow to normal speed) was studied by several research partners [246,347,350]. • A significant reduction in writing pressure and grip force was reported. • Unfortunately, clinical improvement in fluency and speed of writing was not correlated with objective documentation of a decrease in grip and writing force. • For patients with simple and complex writer's cramp, it has been assumed excessive grip force with the writing utensil was correlated with excessive grip force in all activities of daily living. • Zeuner et al., noted botulinum toxin injections could help decrease grip force in writing. • Schneider et al, [352] carried out a controlled study comparing the grip force with writing and box lifting force by patients with writer's cramp and healthy age matched controls. • While the pen grip force and writing force were significantly greater for patients with writer's cramp compared to healthy controls, there were no significant differences between the two groups in terms of the force applied when lifting boxes of different weights. • This study raises questions about the underlying, generalized state of hyper-excitation (and reduced inhibition). • On the other hand, performing a simple box lifting task does not require the same control as performing a precise, fine motor, alternating movement like writing. **Kinesiotaping** • In a small clinical trial by Pelosin [271], kinesiotaping was used to improve motor control in patients with FHD. • There was a reduction in pain and some improvement in motor control. • In a recent, small controlled cross over trial including 7 musicians with hand dystonia, the benefits of therapeutic kinesiotapingwere compared to placebo taping. • The musicians self-reported no significant benefits of therapeutic kinesiotaping [353]. • Unfortunately, there was no long term follow up and no large randomized trials could be located.

Table 7: Factors Confounding Treatment Effectivess in FHD.

Specific Factors Interfering with Effectiveness of Treatment for FHD
Genetics and family history
Underlying structural anomalies (e.g., reticular adhesions)
Magnitude of neural degeneration/disorganization prior to diagnosis
Current understanding of the etiology of FHD
Other neurological problems (e.g., PD, MS, Stroke)
Systemic medical problems (e.g., diabetes, hypertension, cardiac disease)
Psychological factors (e.g., depression, perfectionism, phobia)
Current research evidence
Duration of signs and syptoms
Adverse responses to early inappropriate treatment
Employer flexibility in return to modified schedule
Poor stress management
Lack of family support
Financial stability
Unhealthy life style (e.g., alcohol, drugs, inadequate exercise, poor sleep)

At this time, no single intervention strategy has been associated with 100% recovery [31,134,152,328]. However, there are self-reports of cures [63]. Most commonly, patients as well as clinicians self-report improvement in function following neural retraining. Unfortunately, objective, kinematic, documentation of reported improvement in motor control has been difficult to measure [31,134,152,328].

In occupations and professions requiring repetitive, work-related tasks, employers and individuals must achieve a critical balance between safe levels of repetitive movements paired with adequate rest, hydration, general exercise, nutrition and stress management. It may be easier to prevent FHD than to effectively manage it. Interestingly, there is a substantial amount of research regarding prevention of injuries in the workplace [355-367]. Unfortunately, there is less than perfect compliance with available prevention guidelines for employers and performers. In addition, many individuals have limited access to health care resources for prevention or rehabilitation.

Summary and Conclusion

FHD is a multifactorial movement disorder. Despite significant research, the etiology is still considered idiopathic. Currently, intervention strategies are focused on management rather than cure. Based on small clinical trials, case reports and case series, patients with FHD can expect to experience improvement in voluntary task specific motor control following a combination of medical management strategies, neural priming stategies and behavioral brain retraining based on the principles of neuroplasticity. Improvement in motor control post treatment typically ranges from 60-90%. While patients and clinician care givers both self-report improvement following comprehensive behavioral training, the subjective improvement reported may not be objectively documented. However, there are no adverse events following behavioral, sensorimotor brain retraining.

Positive trends regarding the effectiveness of sensorimotor behavioral brain retraining strategies have been reviewed in this manuscript. The strength of the evidence is limited by the inclusion of small numbers of subjects, pre-experimental study designs, lack of blinding or randomization, variations in dosage of therapy and limited, intensive supervised training with good longitudinal follow up. Effective behavioral management strategies for patients with FHD must be comprehensive, and individualized to each patient. Every individual with FHD does not face the same neuromuscular, musculoskeletal or psycho-social challenges.

Large, well-controlled, multi-centered basic science and randomized clinical research trials are needed to clarify the intereaction between genetic, neuroanatomical, neurophysiological, musculoskeletal, psychological, life style , and behavioral elements associated with the etiology and retraining of FHD [354]. It is also important for clinicians to understand which factors are most responsive to change and which patients are likely to be responders versus non responders. Clinicians must partner with basic scientists to maximize the accuracy, the sensitivity, the specificity and the integrative potential of the research findings. Ultimately, health care providers must develop evidence based clinical guidelines for effective FHD management (e.g. types of retraining, timing of interventions, intensity of training, duration of rehabilitative activities).

In conclusion, at this time, patients with FHD should work with a team to begin recovery of motor control. Medical management strategies should be paired with neurobehavioral, sensorimotor retraining. It is safe for patients with FHD to engage in active, dynamic, progressive brain retraining based on the principles of neuroplasticity. With motivation, commitment and repetitive practice under supervision and at home, a patient with FHD can expect to achieve 60-80% improvement in task specific motor control,but a cure cannot be guaranteed.

Conflict of Interests

Nancy Byl has served as a voluntary member of the Board of Directors without salary for AlterG.com, Vasper.Com, Scientificlearning.com, Exsobionics.com, Positscience.com

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