SCIENTIFIC/CLINICAL ARTICLE

Focal Hand Dystonia: Effectiveness of a Home Program of Fitness and Learning-based Sensorimotor and Memory Training

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ABSTRACT:
Study Design: This was a pre post test design.
Introduction: Retraining the brain is one approach to remediate movement dysfunction resulting from task specific focal hand dystonia (FHD_{TSP}).
Purpose: Document change in task specific performance (TSP) for patients with FHD_{TSP} after 8 weeks of comprehensive home training (fitness activities, task practice, learning based memory and sensorimotor training).
Methods: Thirteen subjects were admitted and evaluated at baseline, immediately and 6 months post treatment for task specific performance, functional independence, sensory discrimination, fine motor speed and strength. In Phase I, 10 subjects were randomly assigned to home training alone or supervised practice prior to initiating the home training. In phase II, 2 subjects crossed over and 3 new subjects were added (18 hands). The intent to treat model was followed. Outcomes were summarized by median, effect size, and proportion improving with nonparametric analysis for significance.
Results: Immediately post-intervention, TSP, sensory discrimination, and fine motor speed improved 60-80% ($p<0.001$ respectively). Functional independence and strength improved by 50%. Eleven subjects (16 hands) were re-evaluated at 6 months; all but one subject reported a return to work. Task-specific performance was scored 84-90% . Supervised practice was associated with greater compliance and greater gains in performance.
Conclusions: Progressive task practice plus learning based memory and sensorimotor training can improve TSP in patients with FHD_{TSP}. Compliance with home training is enhanced when initiated with supervised practice.
Level of Evidence: 4

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Task-specific focal hand dystonia (FHd_{TSP}) is a type of occupational limb dystonia (e.g., writer's cramp, musician's cramp, golfer's yip, or keyboarder's cramp) characterized by involuntary, end range twisting-type movements that interfere with the performance of a target task.[1–10] Although FHd_{TSP} is still classified as idiopathic, there is increasing evidence that the etiology is multifactorial (e.g., an interaction of genetic, neurophysiological, neuromuscular, auditory, neural adaptive, anatomic, personality, repetitive, psychological, stressful, and/or traumatic risk factors).[3,6,9,11–14] Neurophysiologically, degraded cortical representations, poor spatial and sensory discrimination (SEN), excessive plasticity (sensory and motor), increased neuronal excitability, and inadequate inhibition are reported in subjects with FHd_{TSP}.[15–51]

Although some individuals report full recovery postdiagnosis of FHd, Health care professionals usually consider FHd_{TSP} a chronic problem requiring ongoing management.[52] Local injections of botulinum toxin[53–59] or systemic drugs (e.g., Baclophen and Sinemet) are most commonly prescribed.[52] Surgery may be recommended to relieve local nerve entrapment or tightness of fascia in the hand.[60,61] Psychological counseling,[62] relaxation exercises, and biomechanical education regarding performance

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techniques (with or without biofeedback or instructional lessons) are commonly recommended to complement pharmaceutical intervention strategies.[63–68]

Research evidence strongly supports the benefits of regular exercise for brain and physical health.[69–73] Research also specifically highlights the benefits of learning-based, memory training to slow down the process of aging and maintain high-level cognitive skills and attention.[65–67,70–72,74–89] Specific to FHd_{TSP}, learning-based sensorimotor training (LBSMT) based on the principles of neural plasticity has been positively associated with gains in task-specific performance.[65,66,75,78,80–82,90] Unfortunately, single-focused intervention strategies are rarely associated with 100% recovery of task-specific performance for patients with focal hand dystonia.[66,80–82]

The question is, would combining physical fitness, learning-based memory with sensorimotor training and task practice lead to greater recovery of task-specific motor control in patients with FHd_{TSP}? The purpose of this preliminary study was to engage a small number of patients in a comprehensive, multifaceted program including general fitness, specific memory training and LBSMT, and progressive task practice to determine the effect on recovery of task-specific motor performance. This intervention was designed as a home program. To address challenges of compliance with home training, some participants had the opportunity to initiate the program with supervised physical therapy training to clarify the desired performance strategies and to receive corrective feedback to reinforce learning. To confirm the maintenance of neural learning, task-specific performance was measured both immediately postexercise and six months later.

NULL HYPOTHESES

After eight weeks of home training with a self-paced general fitness program, a standard, progressive memory-training program (BrainFit), a LBSMT program and progressive target practice, it was hypothesized that patients with target-specific FHd would not:

1. improve their ability to perform the target task
2. be more compliant with the home program when it was initiated with supervised practice
3. make greater gains in task-specific performance if they demonstrated high versus low compliance
4. maintain the gains in motor performance six months post home program

EXPECTED FINDINGS

Given the multifactorial etiology of FHd with evidence of excessive plasticity, inadequate inhibition, excessive excitation, degradation in cortical hand representation, and the known physical and mental benefits of general exercise, cognitive training, LBSMT activities, and target practice, significant improvement in task-specific performance was expected to follow an eight-week, comprehensive, multifactorial home-training program. The gains were expected to be greater in subjects participating in a short period of supervised practice and those who were most compliant. Assuming that the gains were a reflection of brain reorganization and learning, performance skills were expected to be maintained for at least six months post home training. Hundred percent recovery of task-specific performance was not expected.

METHODS

Subjects

Males or females between the ages of 18 and 65 years, diagnosed by a neurologist or a hand surgeon with occupationally-related FHd and referred to the Physical Therapy Faculty Practice at the University of California, San Francisco (UCSF) or Chapman University were eligible to participate in the study. The dystonic movements needed to be clearly associated with the performance of a primary target task (e.g., writing, keyboarding, and musical performance). Similar tasks could be affected (e.g., shaving, brushing the teeth, combing the hair, and using utensils). A subject was excluded if he or she had a history of uncontrolled systemic disease, traumatic brain injury, brain tumor, neurodegenerative disease, cognitive impairments, or psychosis. The subjects also had to be able to speak English (or bring an interpreter), come to UCSF for initial and follow-up (F/U) evaluations (2 and 6 mo), have access to a portable PC computer to carry out the brain fitness program, and attend supervised practice sessions if they were randomly assigned to the *Home + Group*.

Subjects were admitted at two different times. In Phase I, ten subjects receiving physical therapy in the UCSF Faculty Practice consented to participate in the study. Prospectively this convenience sample was randomly assigned to the *Home Group* ($n = 4$; home program alone) or the *Home Group +* (Phase I, $n = 6$; home program initiated with supervised practice [30 hours]). Approximately 12 weeks after Phase I was started, Phase II admissions were initiated. Three new subjects with FHd_{TSP} receiving physical therapy in the Faculty Practice at UCSF or Chapman University consented to participate and were admitted to the *Home + Group* in Phase II. In addition, two subjects from Phase I elected to cross over to continue in Phase II as part of the *Home + Group* (Phase II, $n = 5$; home program initiated with supervised practice [25 hours]) (see Figure 1).

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PROCEDURES

Instructions for the Home Program

Each subject was contacted by phone to review the inclusion criteria. If eligible, the subject was scheduled to come to the UCSF Faculty Practice for consent and evaluation. A research assistant performed the baseline evaluation and the F/U evaluations. A research staff member from Positscience or the Department of Physical Therapy and Rehabilitation Science installed BrainFit on the home computer for each subject. All subjects also had an appointment with the physical therapist who outlined the components of the program, explained the principles of experience-dependent neuroplasticity, described the home program, and presented each subject with a training CD and a handbook of written instructions. The BrainFit program included a built-in training module.

In addition to the education and introduction by the physical therapist, the CD and the instructional handbook, the subjects in the *Home + Group* had the opportunity to participate in supervised group practice sessions three hours/d, five days/wk for two weeks (30 hours) in Phase I and five hours/d for one week in Phase II (25 hours). If a patient missed a day of supervised practice, an additional day was scheduled. Training exercises outlined in the instructional handbook were demonstrated and then practiced. Task practice stations were set up. The subjects rotated to each station and the therapist provided feedback about accuracy of performance and how to progress training difficulty. The practice sessions were designed to clarify expectations, answer questions, experience different exercises, and potentially increase compliance.

Dependent Variables

Subjects were evaluated at baseline and postintervention (8 wk and 6 mo). All of the tests used to measure the dependent variables are summarized in Figure 2. At each evaluation, the subjects were asked to perform the target task (writing, typing, and/or instrumental play) while being videotaped. The videos were all sent to trained, blinded graduate students in physical therapy according to a predefined coding instrument used in previous studies.[75,76] In addition to the target task measurement, SEN, fine motor skills, and hand strength (STR) were measured bilaterally. A self-reported inventory on functional independence (IND) was also completed.

The evaluation instruments have been described in detail in previous studies.[76,91,92] All tests were administered according to standard procedures.[19,75,76,90,93–95] The tests had acceptable reliability. On the timed tests, a ceiling value was established in advance to permit standardized scoring (see Table 1).

Subtests from the Sensory Integration and Praxis Test (kinesthesia and graphesthesia)[96] and the Byl–Cheney–Boczai Discriminator Test (BCB-stereognosis)[94] were administered to measure cortical SEN. The scores on these two tests were calculated as % incorrect and were added together to create the *Sensory Score*. The *Fine Motor Score* was the summary score from performance on the Digital Reaction Time Test and the Tapper Test. For the Digital Reaction Test, the subject had up to 60 seconds to click a stopwatch on/off. Three trials were administered for each digit and then the speed was averaged across all of the digits. On the Tapper Test, the subject was instructed to repeatedly depress the lever as fast as possible in 10 seconds. The number of taps was averaged for each finger and across the fingers for each hand.

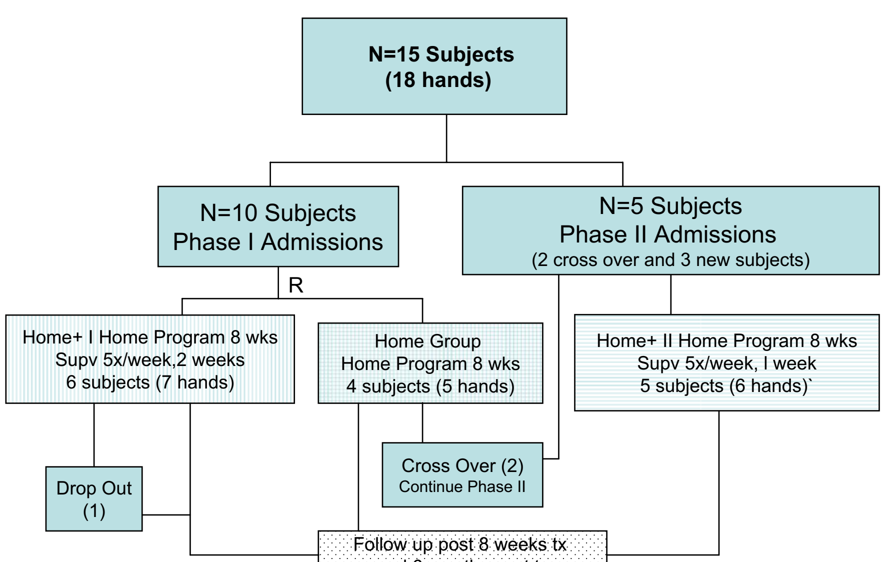

FIGURE 1. A total of ten subjects enrolled in the study in Phase I. An additional three subjects enrolled in Phase II and two subjects from Phase I crossed over to the Home + Group, creating 15 participants (18 hands). One subject dropped out.

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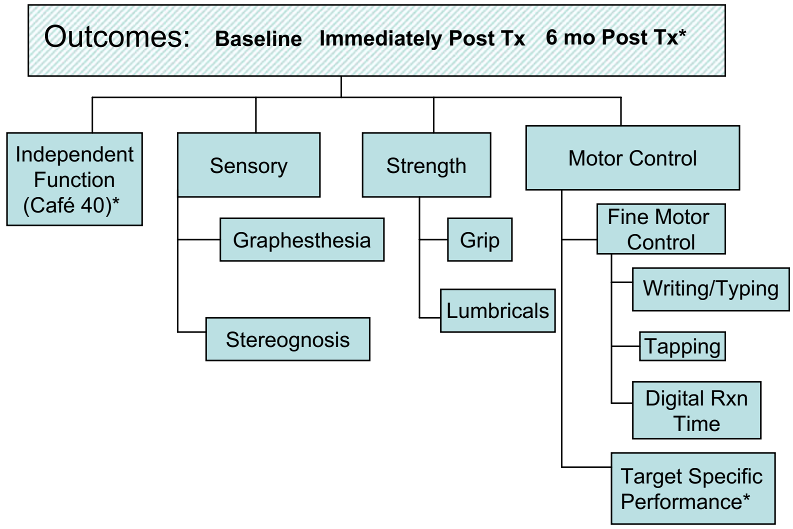

FIGURE 2. *The dependent variables were measured at baseline, immediately posttreatment and six months posttreatment.*

The score was determined by subtracting the average score from 70, the norm determined from previous studies.[76] The *Fine Motor Score* was the sum of the average score on the Digital Reaction Test and the average score on the Tapper Test. In previous studies, interrater reliability was high (intraclass correlation coefficient [ICC] = 0.994).[19] *IND* was measured with the self-rated California Functional Evaluation (CAFÉ 40).[95] Forty items were scored from zero to seven based on amount of help needed and the ability to perform common household, self-care, and work tasks. The average score is 83.7% in healthy adults.[95] Grip and pinch STR as well as the STR of the lumbrical muscles[97] were tested according to standard procedures for manual muscle testing using a grip and a hand-held dynamometer (measured in pounds). The average STR of three trials for each task was added together to create a *STR Score*.[98,99]

Interventions

All subjects were asked to think positively about recovery and to try and manage personal and professional stress to allow them to concentrate on retraining. The subject was asked to try to cease the abnormal movements. The home program included four components: 1) fitness exercises (positive health), 2) memory training using a progressive, computerized commercial program based on the principles of neuroplasticity (BrainFit), 3) LBSMT on nontarget and target tasks emphasizing sensory processing with feedback through mirrors, sound, sensation, and myoelectric biofeedback, and 4) specific progressive learning-based practice on the target instrument (good biomechanics, healthy techniques, and minimal stress). Each subject was asked to follow the specific instructions included for the memory training—BrainFit (1 hour/d) and carry out learning-based sensorimotor exercises on nontarget and target tasks for 1 hour/d.[90] Some of the subjects were also taking music lessons with a trained teacher and were allowed to continue this instruction during the study.

Physical Fitness

Each subject was allowed to define their own fitness exercise program according to the following guidelines: 1) exercise for conditioning and wellness 3–5 times a week for 30–40 minutes (heart rate targeted at 80% of maximum [200 − age × 80%] achieved by walking, running, riding a bicycle, swimming, or doing a workout in the gym), 2) get adequate sleep (5–8 hours of sleep/night), 3) maintain hydration (10–12 glasses of water or juice/d), and 4) eat three meals a day balanced with protein, vegetables, and carbohydrates (not specifically prescribed). This fitness routine was reinforced in the handbook. If the subject asked for more advice on fitness activities, the subject was contacted by the physical therapist.

Brain Fitness

BrainFit (http//www.Postscience.com) is a learning-based memory program designed by scientists at Positscience. This computer-based program included 40 hours of progressive, rewarded, directed, auditory, and spatial perceptual and cognitive games designed to improve memory. Each training module was 15 minutes. The BrainFit program begins with an introduction discussing brain plasticity and includes a practice module. The program was modeled after a learning-based program strategy for children with dyslexia and then modified to enhance memory skills in the elderly. The program is progressed according to performance. The training modules are the same for each individual participant, but the

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TABLE 1. Description of Tests and Measures

Measurement Tool	Dependent Variable	Scoring System	Directions	Reliability	Equipment
Graphesthesia (Modified Subtest of Sensory Integration Praxis Test [SIPT])	Sensory performance	2 = correct 1 = partially correct 0 = incorrect; % error	Tip of a paperclip used to draw designs on subject's fingers while EC. Subject recreates design with pen with EO. Two designs per finger pad	Interrater = 0.95, test–retest $r = 0.91$	Paperclip and design sheet
BCB for stereognosis	Sensory performance	2 = correct 1 = partially correct 0 = incorrect; % error calculated	Subject's finger is drawn across the shape twice, EC. Subject's attempts to pick correct shape. Ten trials for 2nd and 4th finger pads	Interrater/ intrarater = 0.995 (ICC), correlation of $r = 0.06$ between BCB and Purdue Test	Twenty designs and test sheet of designs
Digital Reaction Time Test	Fine motor performance	Time in msec, average of all trials (3 trials/ digit)	Subject turns stopwatch on/off as quickly as possible. 3 trials per finger	Intrasession reliability ranged from 0.975 to 0.99; mean time/digit 25	Stopwatch
Tapper Test	Finger tapping speed	Number of taps in 10 sec	Subject depresses a mechanical lever attached to a counter	0.95 in preliminary study with normal adults; average 70 taps/finger in 10 sec	Tapper and stopwatch
MMT	Musculoskeletal performance	Kilograms of force: UE and LE scores total all score	Tests performed following standard procedures[97] supplemented with dynamometer measurements of force output[98,99] Jamar dynamometers, used for grip, key, and pinch grip	$R = 0.887$ multiple correlation with MMT	Jamar Microfet and baseline dynamometers
Posture	Postures	Ordinal scales; coded 2 if fully met the criteria, 1 if partially met the criteria, and 0 if did not meet the criteria	Posture: bony landmarks cited for the line of gravity [97] were coded as 0, 1, and 2 and summed to a total	Test–retest reliability in normal subjects, 0.8	
CAFÉ 40	Functional performance	Seven-pointLikert Scale (1 = least independent and 7 = most independent)	Self-scoring of ability to perform functional activities. Scores inverted for data analysis	Test–retest: $r = 0.971$; average score in healthy adults, 87.4% [95]	Written questionnaire

BCB = Byl–Cheney–Boczai Test; LE = lower extremity; UE = upper extremity; MMT = Manual Muscle Test; Tapper = finger tapping speed; EC = eyes closed; EO = eyes open.
All of the tests and measurements followed standardized procedures for administration.

difficulty is individually adapted. The subject receives feedback from the program on the performance on the lesson addressed each day. This program has been correlated with significant improvement in memory skills in older adults.[100,101]

LBSMT

The primary goal of LBSMT for patients with focal hand dystonia is to recover normal voluntary fine motor control at the target task. The LBSMT activities are configured according to the principles of neuroplasticity.[102–104] The strategies used are summarized in the Textbook of Hand Surgery and Rehabilitation[103] with the research supporting the theoretical construct and effectiveness of the strategy published in Pathology and Intervention in Musculoskeletal Rehabilitation.[105] The program of training has also been summarized in other research studies (Table 2).[100,101,106]

The learning-based sensorimotor program begins with imaging normal movement, trying to stop the abnormal movement, learning to interface the hand with the target instrument and then creating attended, progressive, graded, repetitive sensory, sensorimotor, and fine motor movements on nontarget and then small parts of the target task. Ultimately, the subjects progress to practicing complete performance on the target task. The focus on facilitating of voluntary progressive *normal* movements beginning with nontarget tasks distinguishes LBSMT from some of the other task-oriented, forced use paradigms characterized as constraint-induced movement therapy (CI or CIT) or sensory motor retuning (SMT), which includes the use of dynamic splinting to control the fingers during forced use of isolated fingers and then multiple fingers.[65]

The physiological objectives of LBSMT are to drive the neural learning required to stop the abnormal, involuntary dystonic movements, and restore normal task-related performance by: 1) quieting excessive excitation, 2) enhancing inhibition, 3) integrating good biomechanics, ergonomics, and SEN when using the hand at nontarget tasks, and 4) integrating good biomechanics, ergonomics, SEN, and normal motor control while performing the target and related tasks. Sensorimotor retraining emphasizes using sensory inputs (the way the object feels) to improve the gradation of coordinated, fine motor output.

At this time, the exact number of repetitions and the progression of difficulty cannot be precisely defined or monitored in terms of minimal detectable differences. In supervised practice, progression of task difficulty must be based on approximate accuracy of performance (e.g., demonstrating approximately 80–90% accuracy before starting a more difficult task). An outline of the program of training is included in Table 2.

Six-month F/U

All subjects were contacted six months post home treatment. Subjects were videotaped while performing the target task(s). Each subject was asked to complete the self-evaluation of IND (CAFÉ 40), note employment status, and rank compliance on each training component (fitness activities, memory training, sensorimotor training, and task practice). Table 3 summarizes the definitions for the ordinal scale for compliance. Work (employment) status was self-coded as: (0) = working or performing full time without difficulty, (1) = working or performing full time with minor modifications of the task, (2) = working or performing regularly but with difficulty and/or using special techniques, (3) = working or performing part time or occasionally, and (4) = not working or performing.

RESEARCH DESIGN AND DATA ANALYSIS

This was a prospective quasi-experimental design as defined by Campbell and Stanley[107] with two intervention groups. Subjects in both groups participated in the standard home program (*Home Group*). The second group (*Home + Group*) initiated the home program with supervised practice (subgroup I participated in 30 hours of practice over 2 wk and subgroup II participated in 20 hours of practice over 1 wk). The subgroups of the *Home + Group* were tracked separately and together to note possible differences by hours of practice. Based on an effect size of 0.90 determined from previous studies involving LBSMT,[106] with alpha set at 0.05 and beta set at 0.30, a minimum of five subjects were needed in each group to have the power of finding a significant difference.[108]

All dependent variables were considered independent families. Each variable was described by median score. On task-specific performance, SEN, fine motor control, and STR, the proportion of affected hands improving in performance by at least 10% and the associated effect sizes were calculated. Analysis of change in IND was based on the number of subjects (not the number of involved hands). The analysis of significance across all subjects or hands was performed with nonparametric statistics (paired Wilcoxon for pre–post test changes and z-test for proportional differences to determine the significance of the proportion of hands improving). All tests were two-tailed; $p < 0.05$). Because of the small number of subjects or hands, group differences were described by median score, effect size, and the ratio of the effect sizes between the groups. At the six-month F/U, self-reported compliance by subject was analyzed by group assignment and then, for visual analysis, compliance was plotted with improvement in task performance. The *intent to treat* model was followed.

RESULTS

Subjects

Table 4 describes the subjects. Ten subjects were admitted in Phase I and three new subjects were admitted in Phase II. There were a total of 13 different subjects, three females and ten males with an average age of 50 years. All of the subjects had been diagnosed with FHd_{TSP} for more than three years. Three subjects had both hands involved. Two subjects from Phase I continued to participate in Phase II of the study, increasing the total participants to 15 (18 hands). One subject dropped out after his car was vandalized during the first week of supervised practice. One subject fractured the unaffected wrist near the end of the eight-week home training (unrelated to treatment) but was available for the immediate posttreatment F/U and the six-month F/U. One subject did not respond to telephone or written requests to return for the six-month F/U.

Effectiveness of Treatment

Immediately after treatment, 50–89% of the subject hands demonstrated statistically significant improvement on SEN (88% improved; $p < 0.005$),

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TABLE 2. Summary of Program Components: Learning-based Sensorimotor Training

I. *Think positively about recovery*

Approach retraining with a positive expectation for improvement.

II. *Image normal movements*

Image normal movement strategies at the desired target task, inhibit involuntary movements (e.g., excessive excitation) and heighten the accuracy of sensory discrimination to facilitate the desired movement. Think back in time when it was possible to perform the target task normally without the involuntary dystonic involuntary movements as well as recapture the joy of performance on the instrument.

III. *Inhibit abnormal movements*

Cease the repetition of the abnormal movements. Be sensitive to even the slightest abnormal muscle contractions (e.g., the tension that may develop while thinking about the task). Reinforce stopping (inhibiting) the abnormal movements with biofeedback (e.g., tape on the affected digits, mirrors, electrical or auditory feedback, visual feedback). Initially, the objective may be just to decrease the frequency of the abnormal dystonia movements. Normal movements must occur more frequently than the abnormal movements.

IV. *Improve sensory discrimination skills*

The objective is to improve the ability of the sensory receptors to actively discriminate fine differences between objects without using the eyes. Sensory information helps inhibit abnormal sensations. Sensory feedback helps develop the ability to modify the movement. Sensory discrimination activities can be done in a variety of venues. For example, putting rough or sticky surfaces on objects you regularly use (e.g., pen, pencil, toothbrush, and hairbrush) can help improve the definition of the object. When an object has a rough surface, the brain will organize itself around the sensation. The brain will automatically reduce the force on an object of similar size and weight if it has a rough versus a smooth surface. Putting specific objects into a bowl with beans, rice, and other stimuli provides a media for the fingers to try to find and match target objects from the bowl. Putting objects in the pocket provides a method to work on sensory discrimination while walking or sitting. It may also be helpful to improve discrimination when information is delivered to the skin by a person or a robotic device. For example, a friend could touch a finger and ask the subject to identify which finger was touched. Another person could draw designs on the finger of the individual with dystonia or write letters or words. The tasks should be progressed in difficulty.

V. *Develop strategies for positive feedback of healthy performance*

To provide feedback for sensory, sensorimotor, and motor training, the unaffected hand can be placed in front of a mirror (the affected hand placed behind the mirror). The mirror image of the unaffected hand looks like the affected hand. This mirror image is used to guide and positively reinforced normal sensation and normal movements of the affected limb (e.g., feeling and discriminating how objects feel, opening and closing the fingers, bending and straightening the wrist, tapping an individual finger, rolling the palm up and down, picking up objects, stacking objects, placing objects in different positions, drawing, writing, and where possible using the target instrument).

VI. *Normalize muscle contractions when the hand is placed on the target instrument*

It is important to learn to place the hand on the target instrument without recruiting muscle tension or the abnormal movements. It may be necessary to imagine placing the hand, then placing the hand for very brief seconds and then increasing the time. A normal balance of sensory activation of receptors must be achieved without abnormal activation of muscle firing.

VII. *Practice grading movements*

Graded movements are practiced to enhance fine motor control at simple and complex tasks. If graded movement can be accomplished at a simple task, it is the first step at achieving controlled graded movements of a more difficult task, including the target task. This skill can be practiced by lightly touching a table surface, putting the fingers on a moving surface like a record turning without changing the music or putting the finger/hand on a scale and maintaining an even pressure. These activities can be progressed to manipulating objects on a moving surface (e.g., on a treadmill moving at different speeds). These skills are needed when using an instrument. Most instruments require fine, graded movements to depress keys, release keys, jointly move fingers up and down on a string or coordinate individual and joint finger depression and release on a keyboard.

VIII. *Practice at nontarget tasks*

Each subject is encouraged to identify the tasks that are similar to the tasks that lead to the dystonic movements. These nontarget tasks are at risk for ultimately being associated with the dystonia. All of the principles of sensory discrimination, healthy contact with the surface of the instrument, manipulation of the instrument, graded handling of the instrument can all be incorporated by working with a nontarget task. These activities reinforce normal movement strategies that can slowly be transferred to the target task.

IX. *Modify the performance posture*

It is important to evaluate the ability to process task-specific sensory information associated with motor performance of the target task in the usual performance position versus a different position. The position of the body relative to gravity can change the information about muscle length, joint proprioception, and postural righting. These modifications in sensory inputs may improve the ability to inhibit abnormal muscle contractions Positions such as lying on the back, the stomach or assuming an inverted position could be tried. In these altered positions, place the hand at the interface of the instrument and then begin to handle the instrument. It may or may not be possible to play in this position. Earning-based sensorimotor activities not only emphasizes sensory discrimination (cutaneous information, muscle length, and joint proprioception) in the usual performing posture, but also may necessitate task practice under different postural conditions (e.g., atypical performance position and inversion).

X. *Fine motor movements*

Fine motor movements are practiced after improving sensory discrimination. The goal is to recruit desired muscles (those moving the fingers and wrist in the desired direction-agonists) while avoiding the contraction of the muscles that move the limb in the opposite direction (trying to stop the muscles from contracting that move the limb in the opposite direction—inhibit antagonists) One example would be to bend the fingers by moving the large knuckle (the base of the finger) by using the muscles inside the hand rather than the longer flexor muscles that bend the fingers (e.g., interossei and lumbricals). Then individuals should practice releasing the muscles used to move the fingers down without necessarily actively lifting the fingers up; this strategy minimizes the rapid, alternating contraction of the muscles that bend and extend the fingers. Practice sessions can be enhanced with auditory and mirror feedback. These movements should be practiced on nontarget and eventually target tasks.

XI. *Practice at target tasks*

Specific task practice must be tailored to each individual and the unique involvement of the dystonic digits and the requirement of performance on each instrument. When the hand can be placed quietly on the target instrument without facilitating abnormal dystonic movements, sensory and fine motor training should be started on the target instrument. In training, the emphasis must be on the integration of nonstereotypical movements, specifically avoiding rapid alternating, stereotypical movement patterns.

(*continued on next page*)

TABLE 2. (*continued*)

Subjects are encouraged to use the whole arm within a balanced posture to perform small quick movements initiated by the muscles originating in the hand instead of the muscles originating in the forearm. Where possible, subjects are encouraged to work with teachers, physical therapists, and ergonomists to incorporate good biomechanics and positively modify techniques on the desired instrument. Individuals with writer's cramp or keyboarder's cramps are encouraged to integrate voice-activated software systems into the work place. However, the benefit of this strategy was not assessed in this study.
The objective of retraining is to positively retrain neural organization and synaptic connections. Quality movements are considered essential, even when only part of the task can be performed. Recommended practice with the target instrument is suggested at 5-min intervals. Regular breaks are considered critical, not only at the beginning of retraining but also until full return to performance is achieved. Breaks are initially recommended at 5-min intervals and progressed to 10-, 15-, 20-, and then 30-min intervals. Even with full return to performance, regular breaks continue to be recommended at every 30 min.
The objectives of learning-based sensorimotor training were to stop the involuntary dystonic movements, decrease over-excitation, facilitate inhibition, enhance accuracy of sensory discrimination, improve voluntary control of the hand, and restore task-specific performance.

Target-specific performance (TSP) (75% improved; $p < 0.006$), and motor speed (76.5% improved; $p < 0.005$). Fifty-three percent to 59% of the subjects had improved scores on IND and STR, respectively, but the gains were not statistically significant (see Figure 3).

Immediately posttreatment, for task-specific performance, the hands of the subjects in *Home + Group* (*I and II*) improved more than the *Home Group* on the affected and unaffected sides. However, the hands in the subjects in the *Home Group* made greater gains in SEN, fine motor speed, and STR. A summary of the median pre- and posttest scores for the affected and unaffected limbs are reported in Table 5 with the effect size changes summarized by group in Table 6.

At six months, the mean score on IND across subjects and across groups was similar to healthy controls (with a mean of 87.4%, 90.0%, and 83.2%, respectively, by *Home + I*, *Home + II*, and *Home Group*). The effect size was 1.09 across groups (1.33, 0.825, 1.35, respectively, by *Home + I*, *Home + II*, and *Home*). At six months, the median TSP score was 79.8% (75.6, 86.9, and 77.3, respectively, by *Home + I*, *Home + II*, and *Home Group*). The effect size for TSP was 1.16 across all three groups (1.81, 1.29, and 0.637, respectively, by *Home + I*, *Home + II*, and *Home Group*). The ratio of the effect size for the two experimental groups (*Home + I* and *Home + II*) compared with the *Home Group* was 2.84 and 2.03, respectively. The subjects in the *Home + Group* were twice as likely to make gains on task-specific performance compared with the *Home Group* (see Table 6 and Figure 4).

Compliance

Table 7 summarizes the level of compliance by group at the six-month F/U. For data analysis of TSP by compliance, the compliance information provided by the subject was integrated to create two groups: a minimally compliant group (no to low compliance) and a moderate to high compliance group (including full to a moderately high compliance). Moderate to high compliance was reported for 33% of the subjects in the *Home Group* and 67.7% of the subjects in the *Home + Group*. The subjects in the *Home + Group* were twice as likely to self-evaluate their compliance as moderate to high compared with subjects in the *Home Group*. There were no differences in median change scores or effect size for IND (effect size 1.1 and 1.2, respectively) for subjects in the moderately high compliant group versus minimal compliant group. However, for TSP, the mean effect size was 3.95 for subjects classified in the moderate to high compliance group and 0.834 for those classified as the minimal compliance group. Subjects who were compliant were four times more likely to improve task performance compared with subjects who had low compliance (see Figure 5).

TABLE 3. **Ordinal Scale for Self-Compliance**

Score	*Definition of Compliance Level*
0	Practiced for a short time every day
1	Practiced regularly (e.g., 3–5 times/wk)
2	Practiced the exercises regularly when having difficulty with the task
3	Occasionally practiced some of the activities
4	Usually did not comply with the activities

At the six-month F/U, of the 11 subjects contacted, six subjects self-rated his or her dystonia as severe and severely disabling at baseline. At F/U, all but one subject had returned to work (including return to musical performance). All six subjects in the moderate to high compliance group rated their initial dystonia as mild and self-reported good to excellent progress, with improvement rated at >50%. All five subjects in the poor compliance group rated their initial focal hand dystonia as severe and reported minimal improvement with the intervention.

Disability

At the beginning of the study, one subject was on work-related disability and two subjects had temporarily taken time off work for retraining. At the end of the study, one subject remained on work-related disability and was eligible for retirement in one year. The remaining ten subjects contacted were working. None of the subjects rated their dystonia as *worse*. When asked if the training had helped to improve their performance at the target task, seven of 11 felt they had experienced a *good*

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TABLE 4. **Description of Subjects**

Group	*Gender*	*Number (Hands)*	*Age Range (yr)*	*Affected Side*	*Occupation*
Home + Phase I[a]	Males: 4 Females: 2	7	27–66	Right: 3 Left: 3	Musician: 2 Translator: 1 Accountant: 1 Administrator: 1 Keyboard/programmer: 1
Home + Phase II[b]	Males: 4 Females: 1	6	37–58	Right: 4 Left: 2	Musician: 5 Keyboard/programmer: 1
Home	Males: 4 Females: 0	5	34–64	Right: 4 Left: 1	Musician: 1 Investment/developer: 1 Health care professional: 2

Total $n = 15$ (18 hands; mean age of 47.6 yr).
[a]One drop out.
[b]Two cross over subjects.

to excellent response to the learning-based training activities. Nine of 11 subjects achieved a score equivalent to healthy age-matched controls (87% or higher) on IND and a score of 85% or higher on TSP.

DISCUSSION

Subjects with FHd_{TSP} can improve task-specific motor control after a comprehensive, integrated home program of fitness exercises, learning-based memory, and sensorimotor training and task practice. Null hypotheses 1–4 must be rejected. Subjects with FHd_{TSP} made significant gains in TSP with home training. Subjects initiating the home program with supervised practice were more likely to be compliant with a home program. Compliant subjects made greater gains in TSP compared with noncompliant patients. Gains in task-specific motor performance were maintained six months posttraining. However, none of the subjects achieved 100% of recovery.

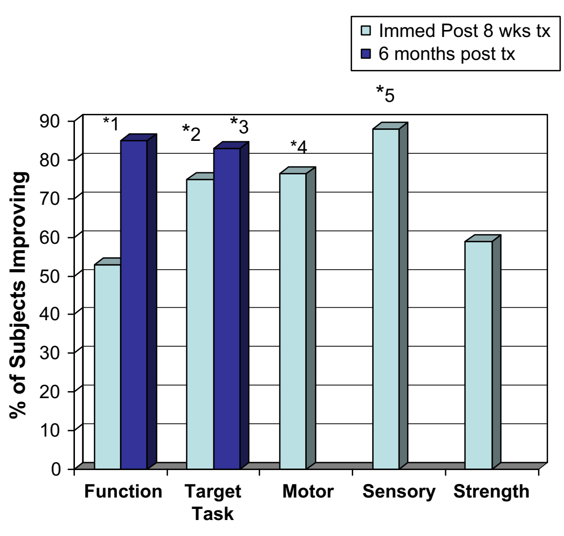

FIGURE 3. *Seventy percent of the subjects improved on all of the dependent variables. The proportion of improvement of the involved hands ranged from 50% to 89%. The proportion of improvement was significant for sensory discrimination (88% improved; $p < 0.005$), target-specific performance (75% improved; $p < 0.006$), and fine motor speed (76.5% improved; $p < 0.005$).*

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The etiology of FHd_{TSP} is multifactorial. Improvement in task performance interacts with chronicity of dystonia, severity of dystonia, motivation of the individual, positive thinking, ability to modify stress and work demands, ability to modify performance techniques, financial stability, family support, and compliance in training. Thus, this preliminary study suggests retraining should be multifactorial. However, multifactorial training limits the ability to confirm which components of training are critical to recovery. It also makes the intervention more challenging to control in a community- or home-based setting.

In this study, half of the subjects rated his or her dystonia as mild and half rated his or her dystonia as severe. Although all of the subjects initially agreed to be compliant with a home learning-based training program, all subjects admitted they were not 100% compliant. Those with less severe dystonia appeared to be more compliant than those self-rating their focal hand dystonia as severe. It is possible that the subject who perceived his or her dystonia as severe may have had more difficulty in thinking positively about recovery, particularly if he or she had suffered dystonia for a long period of time.

Retraining the brain implies that normal movements should be repeated more frequently compared with abnormal movements. Subjects volunteered that it was difficult to stop the abnormal movements, particularly if the subject had to maintain a regular work schedule. The subjects also commented reducing work time helped stress management.

Supervised Practice

The results from this preliminary study suggest that subjects engaging in a supervised program before initiating the home exercise program targeted to retrain the brain were more likely to recover task-specific

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TABLE 5. **Median Scores on Affected and Unaffected Sides by Group**

Measurement/ Period/Group	*Task Performance (%)*		*Sensory (% Incorrect)*		*Fine Motor (Speed of Response)*		*Strength (#)*	
	Affected	*Unaffected*	*Affected*	*Unaffected*	*Affected*	*Unaffected*	*Affected*	*Unaffected*
Home + I								
Pre	63.5	89.0	93.8	87.5	49.6	34.3	106.5	121.4
Post	84.5	100	91.3	76.3	32.1	26.1	106.0	124.7
Home + II								
Pre	86.5	90.0	75	100.0	29.8	22.8	111.8	138.8
Post	71	90.5	63.8	70.0	25.6	26.2	117.7	140.3
Home								
Pre	65.2	79.2	97.5	100.0	19.7	26.8	135.6	141.8
Post	81.1	81.8	97	94.8	22.8	38.7	145.2	134.2
Norm		100		48		19–25[a]		variable

[a]The Total Fine Motor Score for each subject was calculated by subtracting the average number of taps/finger from the norm of 70 and adding the average reaction time/finger.

performance than subjects initiating the home-retraining program with verbal instruction but no practice. The subjects participating in supervised practice were also more compliant. Further, increased compliance was associated with greater gains in TSP.

Home-retraining programs are cost-effective, but compliance is usually an issue. With a home program, it is difficult to provide feedback about accuracy of performance. Thus, training could continue to reinforce abnormal movements. It is also difficult to control practice intensity with a home program.

Intensity of Practice and Compliance

Subjects were asked to join a gym or perform fitness training on a regular basis (l hour 3–5 times/wk, 30–40 min). BrainFit is a program including 40 hours of training. The team at positscience.com recommends daily practice for approximately one hour a day. In addition, subjects were asked to practice LBSMT for one hour a day. It is not clear what intensity (frequency, duration, and type) of practice is needed for subjects to retrain neural networks to restore TSP. Although researchers report a single event can lead to adaptive neurophysiological changes, each synaptic modification may not be associated with improved function.

Most of the patients completed fitness training 3–5 times/wk. However, in terms of sensorimotor or task-specific training, the subjects self-reported spending an average of 30 min/d on the BrainFit program and another 30 min on LBSMT approximately five days a week. Most subjects also reported some self-directed practice with their instrument. Although this time commitment was less than recommended, marked improvement was measured in task-specific performance for both groups of subjects.

From previous studies on forced use paradigms, there is evidence that eight hours of daily training for ten days can lead to significant gains in upper limb function in patients poststroke.[109] However, in these studies, each subject only spent 3.95 of the eight hours

TABLE 6. **Group Results by Mean Change Score and Effect Size**

Pre/Post Change/Group	*Functional Independence*	*Task-specific Control*	*Sensory Score*	*Fine Motor Speed*	*Strength*
Home + I ($n = 6$)					
Mean change score (%)	8	29	−2	−27	−3
Effect size	0.229	4.20	−0.055	−1.35	−0.324
Home + II ($n = 5$)					
Mean change score (%)	6	−10	−10	−14	4
Effect size	0.499	−0.493	−0.221	−0.615	0.845
Home ($n = 5$)					
Mean change score (%)	25	18	18	−3	−0.4
Effect size	0.447	3.43	0.942	−0.130	−0.036
Mean weighted effect size	0.379	2.42	0.166	−0.722	0.263

Immediately Posttreatment. *Across groups:* For IND, there was a moderately large effect size; for task-specific motor control, there was a moderately strong effect size; for fine motor control, SEN, and STR, there was a small effect size. *By group*: *For Group I*, there was a large effect size in task-specific motor control and fine motor control; *for Group II*, there was a moderately strong effect size for IND, task-specific motor control, fine motor control, and a large effect size for strength. *For the home group*, there was a large effect size for task-specific motor control and SEN, a moderate change in IND and a small change in fine motor control and strength.
IND = functional independence; STR = strength; SEN = sensory discrimination.

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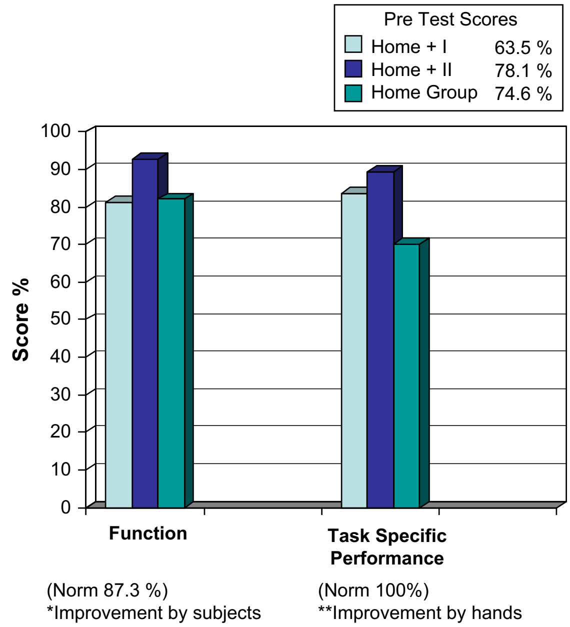

FIGURE 4. At six months posttreatment, 85% of the subjects achieved scores similar to healthy historic subjects on functional independence and 85% of the subjects were performing 85% or higher on the target task.

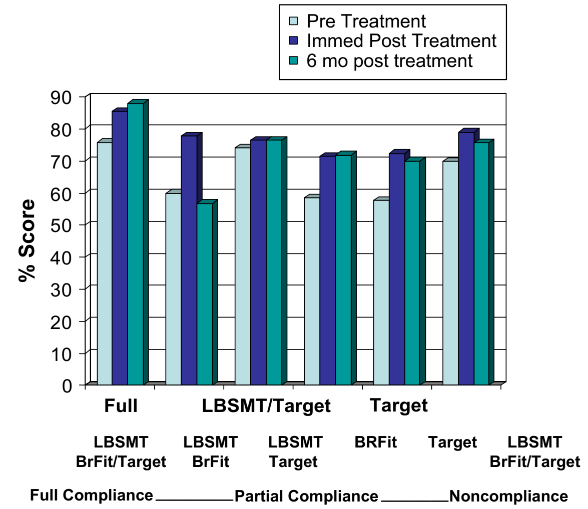

FIGURE 5. At six months posttreatment, subjects self-reporting good compliance achieved greater gains in task-specific motor performance compared with subjects self-reporting poor compliance.

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on task practice (39.50 hours rather than the originally estimated 80 hours). We also know from other clinical studies that greater gains may be achieved during intense periods of training,[106] significant clinical performance gains have also been measured with less intense training (e.g., 2–8 hours/wk for 6–8 wk).

Clinical Significance of Improved Function

In this study, subjects were generally independent in self-care and community integration. However, improvement in IND averaged 20% with 10 of 11 patients functioning similarly or higher than comparable healthy adults (83%). Subjects improved in the range of 10–29% in TSP. On the unaffected side, performance on the target task ranged from 78% to 100%. This suggests that focal hand dystonia has a bilateral impact.

At the six-month F/U, ten of the 11 subjects interviewed had returned to work. Nine of the 11 subjects interviewed were performing at a level of 85–90% on the target task. All reported performing the target task as a component of work. One subject entered the study on disability and remained on disability. This subject was eligible to retire within the year. At the end of the study, this subject was independent in all personal, daily living and community activities and was able to use her computer for personal business. However, using the computer intensively eight hours per day to meet the demands of an accounting career would have been difficult. One subject had been unable to accept any performance commitments before study participation, resumed a regular performance schedule but eliminated one of the instruments in his repertoire.

Neuroimaging studies were carried out on several of the subjects enrolled in this study. Based on magnetoencephalography, there was measurable degradation of the hand representation on the contralateral and ipsilateral side. After training, there was measurable improvement in the organization of the hand representation (improved segregation of the digits). This study is still admitting subjects.

The question is whether combining learning-based memory and sensorimotor training led to greater improvement in task performance compared with LBSMT alone. Comparing the results of this current study with previous sensorimotor training studies of patients with FHd_{TSP}, 100% recovery of task-specific performance is relatively uncommon, even when changes in the cortical map were clearly documented.[19,64–66,75,76,81–83,90] In the previous learning-based sensorimotor studies in our laboratory the recovery of task-specific performance averaged 78.6% with approximately 75% of the subjects returning to work.[19,75,76] In this current study, the recovery of task performance averaged 85% with more than 95% of the subjects returning to work. The criteria for admission of subjects into the current and past studies were the same. However, in

TABLE 7. **Compliance**

Group	*Full Compliance*	*Partial Compliance*	*No Compliance*	*Total*
Home + I	3	2	1[a]	6
Home + II	2[b]	3		5
Home		3	1	4
Total	5	8	2	15

[a]Patient dropped out after car burglarized in the parking lot.
[b]These two patients were crossed over from Phase I.

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the past studies, the sensorimotor training was supervised training once a week reinforced with a home program. Thus, it is unlikely that the differences in the historic findings and the current study were related to severity of impairment. In another study, the same researchers reported significant improvement in cortical representation and digital organization of the hand in patients with FHd_{TSP}; yet, the patients were still making errors in SEN and continued to be slower in motor performance time.[19]

Even though some patients with FHd_{TSP} do not achieve a *cure*, this preliminary study suggests a multifaceted intervention program including fitness and a combination of learning-based memory and sensorimotor training is associated with better recovery of task-specific performance than fitness and LBSMT.

On the other hand, some individuals have successfully trained away $FHd_{TSP.}$ David Leisner, a classical guitarist, claims he not only is cured, but also is performing even better than before the injury. David is a well-known teacher, composer, and performing artist. He freely discusses how he managed to accomplish this after more than ten years with dystonia (www.davidleisner.com/FocalDystonia.html).

Study Limitations

This study had methodological problems limiting the strength of the conclusions and the generalizeability of findings. A mixed quasi-experimental design does not meticulously control the factors needed to assure internal and external validity. Most specifically, this study lacked complete random assignment, double blinding, and a placebo control group. Some control was established by the inclusion of two treatment groups, reference to a historic control group and blinded analysis of the data, particularly the video analysis of TSP. The number of subjects was small and represented a convenience sample of subjects referred to one of two faculty practices in Physical Therapy. Subjects were not restricted from participating in other conventional and unconventional therapies when they participated in the study. Thus, most of the subjects continued to receive physical, occupational, psychological, and/or musical instruction in addition to the study intervention. The study excluded patients who had received botulinum within three months of study participation and subjects were asked not to receive botulinum toxin while enrolled in the study. Only two subjects were able to take time off work to retrain. Continuing to work could have exacerbated the repetition of abnormal movements, limiting the time available to retrain using normal movements. Home exercise programs are inherently at risk for poor patient compliance, even when daily log sheets are included in the study. Compromised compliance limits the ability to interpret the level of effectiveness of the intervention. This study also limits the ability to analyze the requirements of training in terms of intensity, duration, and repetition.

Another major constraint for retraining programs for patients with FHd_{TSP} is that training must follow the basic principles of neural adaptation. However, it must also be tailored to each individual. Thus, the training tasks will vary in terms of the number of repetitions, the progression of difficulty, and the exact activities practiced. In addition, it was not possible to monitor frequency of performance of the abnormal movements. Some patients found it difficult stop the abnormal, involuntary movements during retraining.

Given the small number of subjects and the integration of the *intent to treat* model, the findings in this study must be considered conservative. Even with poor compliance, most of the subjects improved performance on most of the dependent variables. Given the lack of a control group, it is conceivable, improvement in task performance was a consequence of the Hawthorne effect (e.g., increased attention, increased understanding, improved awareness, more directed rehabilitation activities, and increased awareness of the principles of retraining).

Future Research

The findings from this preliminary study provide evidence to support the development of a larger, randomized clinical trial (RCT) to study the effectiveness of neurobehavioral training for patients with $FHd_{TSP.}$ The next trial must include random assignment, blinded evaluators, and supervised intervention for all aspects of treatment (e.g., fitness programs, positive thinking, memory training, and sensorimotor training, and task practice). The subjects should all participate in fitness and wellness activities and then be randomly assigned to participate in one of three learning-based paradigms: 1) learning-based memory training, 2) LBSMT at nontarget and target tasks, and 3) learning-based memory and sensorimotor training. This study needs to be a longitudinal study with at least a one-year F/U. Given the reported effectiveness of 40 hours of BrainFit training, the LBSMT should also be 40 hours (8 wk, 5 d/wk, 1 hour/d). To condense training time, memory training could be performed during a fitness activity (e.g., walking on a treadmill or riding a bike). Combining activities would heighten attention and facilitate dual-task performance. The findings from the RCT could then be translated to a home setting, with telephone calls, Web site chat rooms, and/or camera supported workstation sites to facilitate compliance.

CONCLUSIONS

In this preliminary, quasi-experimental study of patients with FHd_{TSP}, positive gains in task-specific performance were measured after a multifactorial home program emphasizing fitness, cessation of abnormal patterns of movement, enhanced memory skills, and improved sensorimotor discrimination. Patient compliance is an important part of recovery of function. These findings provide evidence to develop larger, RCTs for patients with FHd_{TSP} to tease out the relative importance of each program component and to correlate neurophysiological changes as measured by current neuroimaging techniques with performance gains.

REFERENCES

1. Cohen L, Hallett M. Hand cramps: clinical features and electromyographic patterns in a focal dystonia. Neurology. 1988; 38:1005–12.
2. Jabusch H, Altenmuller E. Epidemiology, phenomenology and therapy of musician's cramp. In: Altenmuller E, Wiesendanger M, Kesselring J (eds). Music, Motor Control and the Brain. New York, NY: Oxford University Press, 2006:265–87.
3. Lin P, Shamim EA, Hallett M. Focal hand dystonia. Pract Neurol. 2006;6:2542–57.
4. Altenmüller E. Focal dystonia: advances in brain imaging and understanding of fine motor control in musicians. Hand Clin. 2003;19:1–16.
5. Altenmüller E. The End of the Song? Robert Schumann's Focal Dystonia. In: Altenmüller E, Wiesendanger KM, Kesselring J (eds). Music, Motor Control and the Brain. New York, NY: Oxford University Press, 2006:251–64.
6. Hallett M. Is dystonia a sensory disorder? Ann Neurol. 1995; 38:139–40.
7. Hallett M. Pathophysiology of writer's cramp. Hum Mov Sci. 2006;25:454–63.
8. Fahn S. Assessment of Primary Dystonias. Boston, MA: Butterworths, 1989.
9. Rosenkranz K, Williamon A, Butler K, Cordivari C, Lees AJ, Rothwell JC. Pathophysiological differences between musician's dystonia and writer's cramp. Brain. 2005;128: 918–31.
10. Rosenkranz K. The neurophysiology of focal hand dystonia in musicians. In: Altenmüller E, Wiesendanger KM, Kesselring J (eds). Music, Motor Control and the Brain. New York, NY: Oxford University Press, 2006:266–84.
11. Meunier S, Garnero L, Ducorps A, et al. Human brain mapping in dystonia reveals both endophenotypic traits and adaptive reorganization. Ann Neurol. 2001;50:521–7.
12. Leijnse J, Hallett M. Etiological musculo-skeletal factor in focal dystonia in a musician's hand: a case study of the right hand of a guitarist. Mov Disord. 2007;51:93–101.
13. Jankovic J. Can peripheral trauma induce dystonia and other movement disorders? Yes!. Mov Disord. 2001;16:7–12.
14. Doidge N. The Brain That Changes Itself. New York: Penguin Group, 2007.
15. Byl N, Merzenich MM, Cheung S, Bedenbaugh P, Nagarajan SS, Jenkins WM. A primate genesis model of focal hand dystonia and repetitive strain injury: I. Learning-induced dedifferentiation of the representation of the hand in the primary somatosensory cortex in adult monkeys. Neurology. 1996; 47(2):508–20.
16. Byl N, Merzenich MM, Cheung S, Bedenbaugh P, Nagarajan SS, Jenkins WM. A primate model for studying focal dystonia and repetitive strain injury: effects on the primary somatosensory cortex. Phys Ther. 1997;77:269–84.
17. Elbert T, Candia V, Altenmuller E, et al. Alteration of digital representations in somatosensory cortex in focal hand dystonia. Neuroreport. 1998;9:3571–5.
18. Jancke L. The Motor Representation in Pianists and String Players. New York: Oxford University Press, 2006.
19. McKenzie A, Nagarajan S, Byl NN. Somatosensory representation of the digits and clinical performance in patients with focal hand dystonia. Am J Phys Med Rehabil. 2003;82(10):737–49.
20. Quartarone A, Bagnato S, Rizzo V, et al. Abnormal associative plasticity of the human motor cortex in writer's cramp. Brain. 2003;126:2586–96.
21. Quartarone A, Rizzo V, Bagnato S, et al. Homeostatic-like plasticity of the primary motor hand area is impaired in focal hand dystonia. Brain. 2005;128:1943–50.
22. Nirkko A, Kristeva R. Brain Activation During String Playing. New York: Oxford University Press, 2006.
23. Bangert M. Brain Activation During Piano Playing. New York: Oxford University Press, 2006.
24. Bara-Jimenez W, Catalan MJ, Hallett M, Gerloff C. Abnormal somatosensory homunculus in dystonia of the hand. Ann Neurol. 1998;44:828–31.
25. Blake D, Byl N, Merzenich M. Sensory representation abnormalities that parallel focal hand dystonia in a primate model. Somatosens Mot Res. 2002;19(4):347–57.
26. Pantev C. Representational cortex in musicians. Plastic alterations in response to musical practice. Ann N Y Acad Sci. 2001;930:300–14.
27. Quartarone A, Siebner HR, Rothwell JC. Task-specific hand dystonia: can too much plasticity be bad for you? Trends Neurosci. 2006;29:192–9.
28. Filipovic S, Ljubiavljevic M, Svetel M, Milanovic S, Kacar A, Kostic VSA. Impairment of cortical inhibition in writer's cramp as revealed by changes in electromyographic silent period after transcranial magnetic stimulation. Neurosci Lett. 1997;222:167–70.
29. Hughes M, McLellan DL. Increased co-activation of the upper limb muscles in writer's cramp. J Neurol Neurosurg Psychiatry. 1985;48:782–7.
30. Levy LM, Hallett M. Impaired brain GABA in focal dystonia. Ann Neurol. 2002;51:93–101.
31. Kaji R, Murase N, Urushihara R, Asanuma K. Sensory deficits in dystonia and their significance. Adv Neurol. 2004;94:11–7.
32. Prebisch C, Erg D, Hofmann E, Solymosi L, Naumann M. Cerebral activation patterns in patients with writer's cramp: a functional magnetic resonance imaging study. J Neurol. 2001;248:10–7.
33. Ibanez V, Sadato N, Karp B, Deiber MP, Hallett M. Deficient activation of the motor cortical network in patients with writer's cramp. Neurology. 1999;53:96–105.
34. Sanger T, Merzenich MM. Computational model of the role of sensory disorganization in focal task specific dystonia. J Neurophysiol. 2000;84:2458–64.
35. Sanger T, Tarsy D, Pascual-Leone A. Abnormalities of spatial and temporal sensory discrimination in writer's cramp. Mov Disord. 2001;16(1):94–9.
36. Nowak D, Rosenkranz K, Topka H, Rothwell J. Disturbances of grip force behavior in focal hand dystonia: evidence for a generalized impairment of sensory motor integration? J Neurol Neurosurg Psychiatry. 2005;76:953–9.
37. Molloy F, Carr TD, Zeuner KE, Dambrosia JM, Hallett M. Abnormalities of spatial discrimination in focal and generalized dystonia. Brain. 2003;126:2175–82.
38. Murase N, Kaji R, Shimazu H, et al. Abnormal premovement gating of somatosensory input in writer's cramp. Brain. 2000; 126:2586–96.
39. Nakashima K, Rothwell JC, Day BL, Thompson PD, Shannon K, Marsden CD. Reciprocal inhibition between forearm muscles in patients with writer's cramp and other occupational cramps, symptomatic hemidystonia and hemiparesis due to stroke. Brain. 1997;112:681–97.
40. Nordstrom M, Butler SL. Reduced intracortical inhibition and facilitation of corticospinal neurons in musicians. Exp Brain Res. 2002;144:336–42.
41. Obermann M, Yaldizli O, de Greiff A, et al. Increased basal-ganglia activation performing a non-dystonia-related task in focal dystonia. Eur J Neurol. 2008;15:831–8.
42. Odergren T, Iwasaki N, Borg J, Forssberg H. Impaired sensory motor integration during grasping in writers cramp. Brain. 1996;229:569–683.

43. Oga T. Abnormal cortical mechanisms of voluntary muscle relaxation in patients with writer's cramp: an fMRI study. Brain. 2002;125(4):895–903.
44. Peller M. The basal ganglia are hyperactive during the discrimination of tactile stimuli in writer's cramp. Brain. 2006; 129:2697–708.
45. Butefisch C, Boroojerdi B, Chen R, Battaglia F, Hallett M. Task-dependent intracortical inhibition is impaired in focal hand dystonia. Mov Disord. 2005;20:545–51.
46. Butterworth S, Francis S, Kelly E, McGlone F, Bowtell R, Sawle GV. Abnormal cortical sensory activation in dystonia: an fMRI study. Mov Disord. 2003;18:673–82.
47. Ridding M, Sheean G, Rothwell JC, Inzelberg R, Kujirai T. Changes in the balance between motor cortical excitation and inhibition in focal, task specific dystonia. J Neurol Neurosurg Psychiatry. 1995;59:304–15.
48. Egger C. Voxel based morphometry reveals specific gray matter changes in primary dystonia. Mov Disord. 2007;22(11): 1538–42.
49. Stinear C, Byblow WD. Role of intracortical inhibition in selective hand muscle activation. J Neurophysiol. 2003;89: 2013–20.
50. Tinazzi M, Fiorio M, Stanzani C, et al. Temporal discrimination of two passive movements in writer's cramp. Mov Disord. 2006;21(8):1131–5.
51. Ridding M, Uy J. Changes in motor cortical excitability induced by paired associative stimulation. Clin Neurophysiol. 2003;114:1437–44.
52. Jankovic J. Treatment of dystonia. Lancet Neurol. 2006;5:864–72.
53. Ceballos-Baumann A, Sheean G, Passingham RE, Marsden CD, Brooks DJ. Botulinum toxin does not reverse the cortical dysfunction associated with writer's cramp. A PET study. Brain. 1997;120:571–82.
54. Das C, Dressler D, Hallett M. Botulinum toxin therapy of writer's cramp. Eur J Neurol. 2006;13:55–9.
55. Sankhla C, Jankovic J, Duane D. Variability of immunologic and clinical response in dystonic patients immunoresistant to botulinum toxin injections. Mov Disord. 1998;13:150–4.
56. Jankovic J, Schwartz K. Response and immunoresistance to botulinum toxin injections. Neurology. 1995;45:1743–6.
57. Hsiung GY, Da SK, Ranawaya R, Lafontaine AL, Suchowersky O. Long-term efficacy of botulinum toxin A in treatment of various movement disorders over a 10-year period. Mov Disord. 2002;17:1288–93.
58. Naumann M, Jankovic J. Safety of botulinum toxin type A: a systematic review and meta-analysis. Curr Med Res Opin. 2004;20:981–90.
59. Djebbarai R, duMontcel ST, Sangla S, Vidal JS, Gallouedec G, Vidailhet M. Factors predicting improvement in motor disability in writer's cramp treated with botulinum toxin. J Neurol Neurosurg Psychiatry. 2004;75:1688–91.
60. Jankovic J. Dystonia: medical therapy and botulinum toxin. In: Fahn S, Hallett M, DeLong DR (eds). Dystonia 4: Advances in Neurology, vol 94. Philadelphia: Lippincott, Williams and Wilkins, 2004:275–86.
61. Charness ME, Ross MH, Shefner JM. Ulnar neuropathy and dystonic flexion of the fourth and fifth digits: clinical correlation in musicians. Muscle Nerve. 1996;19:431–7.
62. Kolle B. Psychological approach to focal dystonia in musicians Commerce Place, 350 Main Street, Malden, MA 02148, USAIn: Tubiana R, Camadio P (eds). Medical Problems of the Instrumental Musician. London: Martin Dunitz/Blackwell Science Inc., 2000.
63. Tubiana R, Camadio P. Medical Problems of the Instrumentalist Musician Commerce Place, 350 Main Street, Malden, MA 02148, USA1st ed. United Kingdom: Martin Dunitz/Blackwell Science Inc., 2000.
64. Baur B, Schenk T, Furholzer W, et al. Modified pen grip in the treatment of writer's cramp: training-induced changes of handwriting kinematics and writing pressure in patients with writer's cramp. Hum Mov Sci. 2006;25:464–73.
65. Candia V, Wienbruch C, Elbert T, Rockstroh B, Ray W. Effective behavioral treatment of focal hand dystonia in musicians alters somatosensory cortical organization. Proc Natl Acad Sci U S A. 2003;100:7942–6.
66. Candia V, Elbert T, Pascual-Leone A. Changing the brain through therapy for musicians' hand dystonia. Ann N Y Acad Sci. 2005;1060:335–42.
67. Cottraux J, Juenet C, Collet L. The treatment of writer's cramp with multimodal behavior therapy and biofeedback: a study of 25 cases. Br J Psychiatry. 1983;142:180–3.
68. Deepak K, Behary M. Specific muscle EMG biofeedback for hand dystonia. Appl Psychophysiol Biofeedback. 1999;24: 267–80.
69. Larsen JO, Skalicky M, Viidik A. Does long-term physical exercise counteract age-related Purkinje cell loss? A stereological study of rat cerebellum. J Comp Neurol. 2000;428(2):213–22.
70. Hassmen P, Cecik R, Backman L. Exercise for older women: a training method and its influences on physical and cognitive performance. Eur J Appl Physiol Occup Physiol. 1992;64(5): 460–6.
71. Fabre C, Chamari K, Mucci P, Masse-Biron J, Prefaut C. Improvement of cognitive function by mental and/or individualized aerobic training healthy elderly subjects. Int J Sports Med. 2002;23:415–21.
72. Bloomquist K, Danner F. Effects of physical conditioning on information-processing efficiency. Percept Mot Skills. 1987; 65:175–86.
73. Begley S. The upside of aging. Wall Street Journal. 2007 Feb 17.
74. Farthing J, Borowsky R, Chilibeck PD, Insted G, Sarty GE. Neuro-physiological adaptations associated with cross-education of strength. Brain Topogr. 2007;20:77–88.
75. Byl N, Nagarajan SS, McKenzie AL. Treatment effectiveness of patients with a history of repetitive strain injury and focal hand dystonia: a planned, prospective follow up study. J Hand Ther. 2000;13:289–301.
76. Byl NN, Nagarajan S, McKenzie AL. Effect of sensory discrimination training on structure and function in patients with focal hand dystonia: a case series. Arch Phys Med Rehabil. 2003;84:1505–14.
77. Byl NN, Priori A. The development of focal dystonia in musicians as a consequence of maladaptive plasticity: implications for intervention. In: Altenmuller E, Mario W, Kesselring J (eds). Music, Motor Control and the Brain. New York: Oxford University Press, 2006:293–308.
78. Rosenkranz K, Butler K, Willimon A, Cordivari C, Lees AJ, Rothwell JC. Sensorimotor reorganization by proprioceptive training in musician's dystonia and writer's cramp. Neurology. 2008;22:304–15.
79. Schenk T, Bauer B, Steidle B, Marquardt C. Does training improve writer's cramp: an evaluation of a behavioral treatment approach using kinematic analysis. J Hand Ther. 2004;17:349–63.
80. Zeuner K, Bara-Jimenez M, Noguchi PS, Goldstein SR, Dambrosia JM, Hallett M. Sensory training for patients with focal hand dystonia. Ann Neurol. 2002;51:593–8.
81. Zeuner K, Hallett M. Sensory training as treatment for focal hand dystonia: a 1-year follow-up. Mov Disord. 2003;18(9):1044–7.
82. Zeuner KE, Peller M, Knutzen A, Hallett M, Deuschl G, Siebner HR. Motor re-training does not need to be task specific to improve writer's cramp. Mov Disord. 2008;23(16):2319–27.
83. Zeunner K, Shill HA, Sohn YH, et al. Motor training as treatment in focal hand dystonia. Mov Disord. 2005;20:335–41.
84. Hill R, Storandt M, Malley M. The impact of long term exercise training on psychological function in older adults. J Gerontol. 1993;48(2):12–7.
85. Ang E, Gomez-Pinilla F. Potential therapeutic effects of exercise to the brain. Curr Med Chem. 2007;14:2564–71.
86. Zimman J. Brain fitness news. Posit Science. January 2008:1–3.
87. Ravaglia G, Forti P, Lucicesare A, et al. Physical activity and dementia risk in the elderly: findings from a prospective Italian study. Neurology. 2008;70(19):1786–94.
88. Potter N, Bain, J. Video games help elderly drivers. ABC News. Accessed Oct 27, 2008.
89. Zelinski E. Brain exercises sharpen memory in older adults. Paper presented at the American Gerontological Society, Nov 19, 2007, San Francisco.

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90. Byl N, Roderick J, Mohamed O, et al. Effectiveness of sensory and motor rehabilitation of the upper limb following the principles of neuroplasticity: patients stable poststroke. Neurorehabil Neural Repair. 2003;17:176–91.
91. Byl NN, McKenzie AL, Nagarajan SS. Differences in somatosensory hand organization in a healthy flutist and a flutist with focal hand dystonia: a case report. J Hand Ther. 2000;13:302–9.
92. Byl NN, Hamati D, Melnick M, et al. The sensory consequences of repetitive strain injury in musicians: focal dystonia of the hand. J Back Musculoskeletal Rehabil. 1996;7:27–39.
93. Bohannan R. Stopwatch for measuring thumb movement time. Percept Mot Skills. 1995;81:211–6.
94. Byl NN, Leano J, Cheney LK. The Byl-Cheney-Boczai sensory discriminator: reliability, validity, and responsiveness for testing stereognosis. J Hand Ther. 2002;15:315–30.
95. Fung S, Byl NN, Melnick M, et al. Functional outcomes: the development of a new instrument to monitor the effectiveness of physical therapy. Eur J Phys Med Rehabil. 1997;7:31–41.
96. Ayers A. Sensory Integration and Praxis Test. Los Angeles, CA: Western Psychological Services, 1989.
97. Kendall F, McCreary M, Provance P. Muscles: Testing and Function. Baltimore, MD: Williams and Wilkins, 1993.
98. TEC. Jamar dynamometer. 60 Page Road, Clifton, NJ 07012, USA.
99. Hogan Health Industries, West Jordan UT. Available at: http://www.hogganhealth.com/microfet-eronomics.php Microfet dynamometer-ergoFET 300.
100. Mahncke H, Connor BB, Appelman J, et al. Memory enhancement in healthy older adults using a brain plasticity based training program: a randomized controlled study. PNAS. 2006;103:12523–8.
101. Mahncke H, Ronstone A, Merzenich MM. Brain plasticity and functional losses in the aged: scientific bases for a novel intervention. Prog Brain Res. 2006;157:81–109.
102. Byl NN, Merzenich MM. Principles of neuroplasticity chapter 26In: Gonzalez EG, Myers SJ, Edelstein JL, Lieberman JS, Downey JA (eds). Physiological Basis of Rehabilitation. Boston, MA: Butterworth and Heinemann, 2000:609–28.
103. Byl NN, Merzenich MM. Focal Hand Dystonia. , vol 2. Philadephia, PA: Williams and Wilkins, 2001
104. Kleim J, Jones TA. Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. J Speech Lang Hear Res. 2008;51:S225–39.
105. Byl NN, Barbe M, Barr A. Repetitive stress pathology: soft tissue injuries chapter 22In: Magee DJ, Zachazewski JE, Quillen WS (eds). Pathology and Intervention in Musculoskeletal Rehabilitation. 2nd ed. New York: Saunders Elsevier, 2008: 707–49.
106. Byl NN, Pitsch E, Abrams G. Effect of intensity of rehabilitation on recovery in patients stable post stroke. Neural Rehabil Neural Repair. 2008;22(5):494–504.
107. Campbell D, Stanley JC. Experimental and Quasi-Experimental Designs for Research. Boston, MA: Houghton Mifflin Company, 1963.
108. Maraschuilo L, Serlin RC. Statistical Methods for the Social and Behavioral Sciences. New York: WH Freeman and Company, 1988.
109. Wolf S, Winstein CJ, Miller JP, et al. Effect of constraint-induced movement therapy on upper extremity function 3 to 9 months after stroke: the EXCITE randomized clinical trial. JAMA. 2006;296:2095–104.