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CASE REPORT

Application of neuroplasticity theory through the use of the *Feldenkrais Method*® with a runner with scoliosis and hip and lumbar pain: A case report

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Abstract Neuroplasticity theory has gained considerable attention in recent years in the professions of medicine, psychology and neuroscience. Most research on neuroplasticity has been in neurology focusing on stroke and other central nervous system disease and injury. Further research is necessary to advance the connection of neuroplasticity theory to musculoskeletal conditions and rehabilitation. The theory of neuroplasticity as it applies to the acquisition of new skills and modification of maladaptive, pain-perpetuating and inefficient movement patterns is fundamental to the *Feldenkrais Method*. This case report demonstrates the application of neuroplasticity theory with the *Feldenkrais Method* as the primary intervention for a 42-year-old female runner with a history of adolescent idiopathic scoliosis who presented with hip and lumbar pain. The client had clinically meaningful improvements in pain intensity and the Global Rating of Change scale while meeting her goals to resume pain free running, repetitive stair climbing at work, and other leisure activities.

Background and purpose

Neuroplasticity theory has gained considerable attention in recent years in the professions of medicine, rehabilitation, psychology and neuroscience. During the twentieth century, the theoretical assumption was that our brain anatomy, function and habits were hard-wired and fixed, and as we aged, the brain lost neurons and therefore an inability to change and learn new skills (Bruel-Jungerman et al., 2007; Doidge, 2007; Flor, 2003; Zemach-Bersin, 2010). Evidence is growing to support the concept that the central nervous system (CNS) encodes new experiences

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and has the ability to change quickly, learn new behaviors and skills, and recover lost functions (Zemach-Bersin, 2010; Flor, 2003; Kleim and Jones, 2008; Boudreau et al., 2010). Most of the research on neuroplasticity has been in the area of neurology focusing on stroke and other CNS disease and injury, while recently evidence is emerging relating it to musculoskeletal conditions (Boudreau et al., 2010; Snodgrass et al., 2014).

Neuroplasticity occurs dynamically throughout the life span with the ability of the nervous system to adapt to stimuli through regeneration and reorganization of its neuronal structure, function and connections. Neuroplasticity can be either adaptive or maladaptive where plasticity risks can result in pathology, dysfunction and chronic pain (Cramer et al., 2011; Snodgrass et al., 2014; Flor, 2003; Boudreau et al., 2010; Pascual-Leone et al., 2005). Maladaptive responses such as learned non-use or disuse, compensatory movements, alterations in movement patterns, and feedback and feedforward mechanisms can be reversed through motor skill training (Kleim and Jones, 2008; Boudreau et al., 2010; Snodgrass et al., 2014; Pascual-Leone et al., 2005; Young and Tolentino, 2011; van Vliet and Heneghan, 2006; Tsao and Hodges, 2008). Task specific training with a whole functional movement, rather than a focus on specific body parts or joints, has been shown to be more effective with neurological conditions. Variety with direction, speed, and positions enhances the transfer of the training to real life (van Vliet and Heneghan, 2006).

Most physical therapists do not consider neuroplasticity of the CNS in their approach to rehabilitation of musculoskeletal conditions, and instead evaluate and treat regional specific movement dysfunction, in contrast to their colleagues who work with neurological dysfunction. As neurological and musculoskeletal disciplines share information towards creation of collaborative models, application of the motor learning principles that bring about cortical neuroplastic reorganization will offer potential for more rehabilitation success for the clients with musculoskeletal impairments (Boudreau et al., 2010; Snodgrass et al., 2014).

The theory of neuroplasticity for learning new skills and modifying maladaptive, pain perpetuating and inefficient habits is fundamental to the *Feldenkrais Method*. Although the *Feldenkrais Method* is one of the lesser known and researched approaches, it has been used by physical therapists and other professionals trained in the method for the recovery of clients suffering from musculoskeletal conditions (Hillier and Worley, 2015).

Integral to the *Feldenkrais Method* is the application of the laws of physics and motion, the learning process, and the manner in which actions are discovered, similar to how children solve the challenges of the physical world to discover new movement (Zemach-Bersin, 2010; Ginsburg, 2010). *Feldenkrais* uses a model of learning showing the interrelatedness of the skeleton, muscles, CNS and environment in a non-causal circular relationship (Ginsburg, 2010) (Fig. 1). Application of the principles of the Weber—Fechner Law, whereby reducing the background noise of muscular effort and pain with slow small movements, improves kinesthetic and sensory acuity. Finer distinctions can then be made to facilitate awareness of unconscious physical organization, movement and action. Once a person can sense what they are habitually doing, the opportunity is present for new skill acquisition, changes in "faulty learning" or habits, and recovery of lost skills in spite of profound brain damage (Zemach-Bersin, 2010).

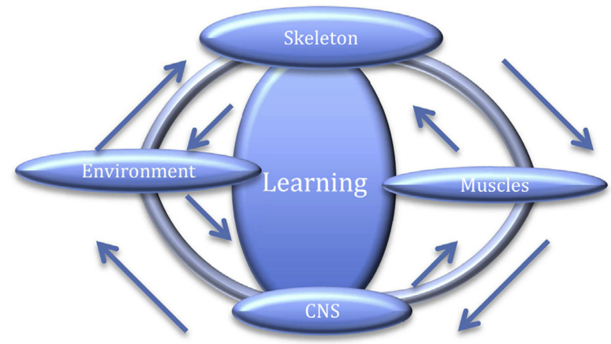

Figure 1 *Feldenkrais* cybernetic loop model of learning, movement and environment.
Adapted from Ginsburg, 2010.

The *Feldenkrais Method* has two modalities derived from the same theoretical basis. *Awareness Through Movement* (*ATM*) lessons, often in a group setting, are verbally guided structured self-explorations of movement designed to bring awareness to sensations accompanying habitual movement patterns from which more efficient and effective functional movement can be learned. Each *ATM* is comprised of approximately 10 variations embedded with learning strategies such as constraints, speed, direction and position to promote discovery of improved functional movement. *Functional Integration* (*FI*) is a hands-on means of gentle tactile, kinesthetic communication to facilitate awareness of habitual behaviors and movement patterns, and foster an expansion of efficient functional movement repertoire. The foundation for *FI* is thousands of *ATM*'s and their variations (Zemach-Bersin, 2010; Buchanan and Ulrich, 2001). Both *FI* and *ATM* have been anecdotally reported to ameliorate the complications related to scoliosis.

Adolescent Idiopathic Scoliosis (AIS) is a three dimensional curvature of the spine that surfaces around puberty, with right-sided thoracic convexities being most common. There are a number of theories, though the etiology remains unclear. Epidemiologic studies show 1—3% of children between the ages of 10—16 will have AIS and most will not require intervention (Weinstein et al., 2008; Parent et al., 2005; Schlösser et al., 2014; Smania et al., 2008). For minor scoliotic curves the ratio with gender is equal, but when the severity of the curve reaches a level requiring treatment, the ratio can rise to 8:1 female to male (Parent et al., 2005). Early detection is important to allow for the opportunity for conservative intervention. Screening is typically performed between the ages of 10—12 with the Adam's forward bend test and a scoliometer (Weinstein et al., 2008; Parent et al., 2005). Trunk rotation $> 7^\circ$ detects nearly all curves $>30^\circ$, but also results in a high number of false positives with many unnecessary radiographs (Parent et al., 2005). Definitive diagnosis is made when a $\geq 10^\circ$ Cobb angle is found on radiographs (Weinstein et al., 2008; Parent et al., 2005). Long-term complications with untreated AIS are curve progression, back pain, cosmetic and psychosocial concerns, and cardiopulmonary compromise (Weinstein et al., 2008). Risk of curve progression can be predicted by age at onset, menarche and adolescent growth spurt (6–8 cm/year); presence of trunk imbalance; size (>30°) and location of the apex of the curve (above T12) with a lower Risser grade (≤1) relating to a worse curve progression (Weinstein et al., 2008; Parent et al., 2005).

Intervention options for AIS are observation, bracing for curves generally between 25° and 45° while skeletal growth is still occurring — Risser grade 0, 1 or 2 (Weinstein et al., 2008; Schlösser et al., 2014; Smania et al., 2008), exercises (Schlösser et al., 2014; Smania et al., 2008) and surgery for curves 40°–50° if still skeletally immature (Parent et al., 2005). The goal with bracing and exercise is to retard curve progression (Negrini et al., 2008) while surgical intervention is for correction and maintenance of the curve (Weinstein et al., 2008). Research is lacking on the effectiveness and efficacy of bracing and exercise (Weinstein et al., 2008; Parent et al., 2005), though a later systematic review with level 1b evidence did show that exercises reduced the curve progression and brace prescription for AIS (Negrini et al., 2008). Considerations for invasive treatment include high cost for surgery and iatrogenic complications. Research is scarce on the management of scoliosis once skeletal maturity has been reached. This case demonstrates *Feldenkrais* as a successful intervention for scoliosis and the musculoskeletal sequelae that may precipitate in adulthood.

Case description

A 42 year-old female runner with AIS experienced a gradual onset of right hip pain over the course of 4 months when she progressively increased the intensity and duration of her training from her normal runs of 3–6 miles to 10–12 miles per day, 4 days per week, in preparation for a marathon. The location of her pain was the right superior, posterior and lateral iliac crest, right upper buttock and right anterior and medial groin regions. On initial presentation she rated her pain on a numeric pain rating scale (NPRS) as a 3/10, with the worst pain a 9/10 "from the pounding of running", and an average 6/10 after walking or ascending and descending stairs. This pain, described as an "ache", lasted two days after each run, and forced her to abort her marathon training. Her occupation as a marketing and special events director required frequent negotiation of stairs. Leisure activity participation included running, yoga, Pilates, telemark and cross country skiing, and snowboarding with a "goofy" footed stance (right foot forward). Her running shoes were one-year old Saucony brand with about 200 miles of wear. She mostly ran on dirt trails and gravel roads facing the traffic on crowned roads. The pain forced her to suspend her program of summer activities of running, stretching, yoga and Pilates and pursue *Feldenkrais* to address her problem.

A school screening revealed scoliosis at 13 years old, her age of menarche. Her physician determined she had AIS with "a curve not significant enough" to warrant radiographs or intervention and she was not observed for curve progression. In her childhood years, she reported always having good balance being active as a dancer, gymnast and swimmer. Eye–hand coordination for ball sports was reportedly not a problem, and occasionally she played tennis, softball and volleyball. There was no family history of scoliosis.

The onset of bilateral lumbar pain surfaced at the fourth visit once the hip pain had diminished. The lumbar pain, noticeable each morning, abated with her morning routine. Her favorite prone sleeping position aggravated her pain, but otherwise sleeping was not a problem.

Review of systems

History and screening questions for all systems were negative with the exception of anemia controlled with diet and foods containing iron, and hypothyroidism controlled with medication. Onset of anemia was during her teen years and was exacerbated by her menstrual cycles and marathon training. After she gave birth to her first child, she was diagnosed with hypothyroidism. She reported an excellent quality of life. Her Patient Health Questionnaire-2 (PHQ-2) score was 0/6 and a PHQ-2 score ≥ 3 has a sensitivity of 83% and a specificity of 92% for major depression (Kroenke et al., 2003). She also took birth control pills and Omega-3's. Caffeine intake was 21 cups of caffeinated drinks per week; alcohol intake was zero to four drinks per week. She did not smoke tobacco or do street drugs. At age 17, she had a right fifth toe bunionectomy with open reduction internal fixation. She had bunions bilaterally of the fifth and first toes with greater severity on the right.

Examination and intervention

The *Feldenkrais* "examination" and the intervention began simultaneously the moment the client walked through the door. As she walked, sat down, talked, and gestured her preferred movement patterns were observed. *Feldenkrais* interview questions were asked such as what she would like to accomplish, what she would like to be able to do better, and how she would know she had met her goal (Table 1). The *Feldenkrais* style of evaluation was blended with a physical therapy examination of physical impairments and functional abilities. See Table 2 for the examination findings and outcome measures at initial visit and upon discharge.

According to the International Classification of Functioning, Disability, and Health Model (ICF) (Fig. 2), the goal of physical therapy is to facilitate functional improvement for return to participation in life activities, health and quality of life. Interventions directed towards the lower levels of the model — pathology, impairment and function — could effect change and improvement at higher levels of function and participation (Daly and Ruff, 2007). The ICF Model was used for goal setting (Table 1) and determining interventions (Table 3). This model fits well with the *Feldenkrais Method* with the central focus and concern of the whole person and their ability to function and participate in life activities.

The *FI* progression addressed the most pronounced "deviations" from the "norm" as they related to her

Table 1 Goals.

Goal	Type of goal (ICF model)	Visit # when goal met
Numeric Pain Rating Scale (NPRS) to 0/10	Impairment	8
Lower Extremity Functional Scale (LEFS) 80/80	Function	8
Oswestry Disability Index (ODI) 0% disability	Function	8
Strength grade 4+/5: glut med/max, hams, trunk, scapula	Impairment	8
Lateral step downs: standard 8 inch step ×10 REPS	Impairment/function	6
Full hip hike ×10 REPS bilaterally (B)	Impairment/function	6
Gait WNL. Walk all day at work/hike for 2 miles w/o pain	Function/participation/activity	7
Stairs: up/down 8 flights for events at work pain-free	Function/participation/activity	8
Running: 2/3 miles w/o pain & 3/3 miles w/o pain	Function/participation/activity	8/9
GROC improved to a +6 of +7 (15 point scale)	Function/participation/activity	9

Abbreviations: repetitions (REPS), within normal limits (WNL), Global Rating of Change (GROC).

functional and life participation goals. Her unique signature movements were her gait pattern, sitting and standing postures. She habitually stood with her right lower extremity forward in ballet fourth position and approximately 70% weight on her left lower extremity with her left hand on her hip, shortened right and lengthened left ribs, and her head turned to the right with the right shoulder forward of the left shoulder. In conversation, her comfortable zone for interaction was for the person, with whom she was speaking, to stand or sit left of her center. In sitting, she was much more comfortable bearing weight on the left sitbone with her trunk and head position similar to standing. Her eyes moved easier to the left and downward, and her head turned easier to left.

With the *Feldenkrais* paradigm there is no set protocol to follow in developing an *FI* lesson plan. Taken into account were the client's unique history, experience, and nuances of her scoliosis and musculoskeletal complications. The *FI* lesson plan was subject to change during each visit, depending on the ongoing and concomitant evaluation and intervention observations and responses. As the client moved passively or actively during the *FI* lesson, continual visual and tactile "listening" observations helped guide the direction of the *FI* lesson. These observations included subtle shifts in sympathetic and parasympathetic nervous system activity such as an alteration in the quality of the client's breathing or movement, changes in muscle tonus or guarding, and other signals of ease and comfort versus anxiety and fear.

Distinctions between the easy and difficult patterns of movement were also part of the determination of progression of *FI* lessons and functional movement themes. The directions of ease and her "deviations" were exaggerated to help her kinesthetically sense and clarify her habit patterns. Directions in which she couldn't move easily were never forced. Later, new ways to move were gently introduced in directions of prior challenge, with greater ease and fluidity. During visit three, side bending in relation to weight shifting was addressed. Initially side bending to the left was very difficult and easy to the right, congruent with her scoliotic curves. During *FI*, the right side bending bias was exaggerated and became even more pronounced. Subsequently, the possibility and ease of side bending to the left spontaneously emerged. Through enhanced kinesthetic recognition of her habit pattern, learning had taken place. Before and after session gait observation showed a significant improvement in shock absorption without "pounding" and collapse during each right side stance phase. Constraint strategies such as a novel position that limited unwanted movements, suggesting new movement options, and a shift away from painful movement habits, were utilized. Some of the significant elements for learning in the *Feldenkrais* paradigm were applied such as exploration, intention, variation (speed, position, direction), novelty, making mistakes, reduction of effort, functional significance, whole versus parts, brief rest periods and visualization. Table 3 Interventions shows the *FI* lesson plan, other physical therapy treatments, client response to the interventions and the home exercise program (HEP) progression.

This client was seen for nine 1-h long visits over a 10-week period. The first two weeks she was seen once per week. Due to slower than anticipated reduction in subjective pain reporting, the frequency was stepped up to twice per week for the next week, and the remaining five visits were tapered down over the last seven weeks. The primary intervention in the clinic was *FI*. Learned concepts were reinforced with repetition and self-exploration through an *ATM* format in an individualized written HEP, later executed from memory (Table 3). The HEP frequency was daily and the number of repetitions per variation within the *ATM* started at five in the first two visits and progressed up to 20 repetitions in the later visits. A new *ATM* was taught each visit, although only one *ATM* was practiced daily at home on a rotating basis. The instruction was to take brief rests of 10–30 s or more as needed to free her attention, do the movements small enough to not go into pain, find the lightness and ease of the movement, while continually identifying and reducing effort. Any temptations to stretch or find the barrier of the movement were avoided. By the fourth visit, she demonstrated the ability to do the *ATM*'s with a quality that satisfactorily met those instructions.

Outcomes

The client's rehabilitation goals (Table 1) of return to running three miles without hip pain, ascend and descend eight or more flights of stairs at work without difficulty, and return to yoga and Pilates classes were met. Several standardized outcome tools were used to measure the effectiveness of the interventions. See Table 2 for a comparison of initial and final visit status for self-report outcome tools,

Table 2 Examination findings and outcomes measures.

Test/outcome measure	Initial findings	Discharge findings
Numeric Pain Rating Scale (NPRS)	Best: 3, worst: 9, average: 6/10	Hip: 0; low back 0, worst: occasional 3/10 in a.m., resolves w/in 2 min when out of bed.
Lower Extremity Functional Scale (LEFS)	74/80	80/80
Oswestry Disability Index (ODI)	4/50 = 8% disability (administered visit #4)	50/50 = 0% disability
Global Rating of Change (GROC)	–	+6/7 = "A great deal better"
Lumbar range of motion	FWB 75% + pain OP, +pain return to neutral; BWB 30% + pain at end range; unable to reverse low lumbar curve, +pain OP; R SB limited + pain OP; L SB w ease -pain OP.	WNL in all directions and no pain with OP.
Hip passive range of motion (PROM)/shoulder active range of motion (AROM)	PROM: L hip WNL, R ↑ tone/guarding in R hip muscles/resists movement in all directions. Shoulder flexion AROM: R 158°, L 148°.	No guarding, free to move in all directions B Shoulder flexion 175° B
Adam's Forward Bend Test	Mild L upper T spine rib hump, R mod/severe mid/low T spine. (Scoliometer unavailable)	–
Strength – Manual Muscle Test	UE's/LE's gr. 5 except glut max/med/hams R gr. 3 + and L gr. 4, back ext/abdominals gr. 4, Lower trap R gr. 3+, L gr. 4-.	Glut max/med and hams/back ext/abdominals gr. 5 B, Lower traps R gr. 5, L gr. 4+.
Single leg stance/balance with challenges	L LE – excellent – stands tall (skeletally aligned) R LE – fair – SB's in Lumbar spine, slight + Trendelenburg & hip adduction, toe flexion to grip, sway and arm movement.	B SL stance – excellent. Quiet, tall stance, skeletally aligned.
Gait	Hard impact heel strike/collapses w downward vertical displacement/shorter stride on R. Little to no pelvic, spinal movement or arm swing except R arm excessive posterior movement.	Fluid gait, even stride/cadence. Min/no vertical displacement of head R:L stance phase. Pelvis moves all 3 planes. Arm swing B – still a little more R posterior arm swing than L.
Posture	R ilium ~4 cm ↑; L shoulder ~5 cm ↑; L earlobe ↑ ~1.25 cm; Flat T and L spine; Space between 12th rib and iliac crest R, 1 finger width, L $2^{1}/_{2}$–3 finger widths. Mild pronation B.	R:L ilium even, L shoulder ~1 cm ↑. Earlobes level. Space between 12th rib and iliac crest ~2 finger widths B.
Pelvic obliquity/flexion and extension dysfunctions of spine	L pube ↑; L anterior innominate, left on right rotated sacrum; R upslip; extended sacral base; L3 FSRL, T8 FSRR + pain to palpation; T2 FSRL; T11 ESRL, T4 ESRL.	–
Leg length	LLE .5 cm longer than RLE (ASIS to inferior medial malleolus) supine & sitting.	–
Mobility testing of spine	PA general hypomobility in thoracic spine and especially T4, T8, T12, L1	–
Stairs	R Hip pain going up/down 1 step	Unlimited stairs (8 + flights) at work for events
Dermatomes, myotomes, reflexes	All WNL B LE	WNL B
Hip scour/SI joint compression–distraction/sign of the buttock	Negative B	Negative B

Abbreviations: forward bending (FWB), backward bending (BWB), overpressure (OP), side bending (SB), upper extremity (UE), lower extremity (LE), bilateral (B), single leg (SL), right (R), left (L), lumbar 3 (L3), flexed sidebent rotated left (FSRL), flexed sidebent rotated right (FSRR), thoracic 2 (T2), thoracic 11 (T11), extended sidebent rotated left (ESRL), thoracic 4 (T4), posterior–anterior (PA), within normal limits (WNL), sacroiliac (SI).

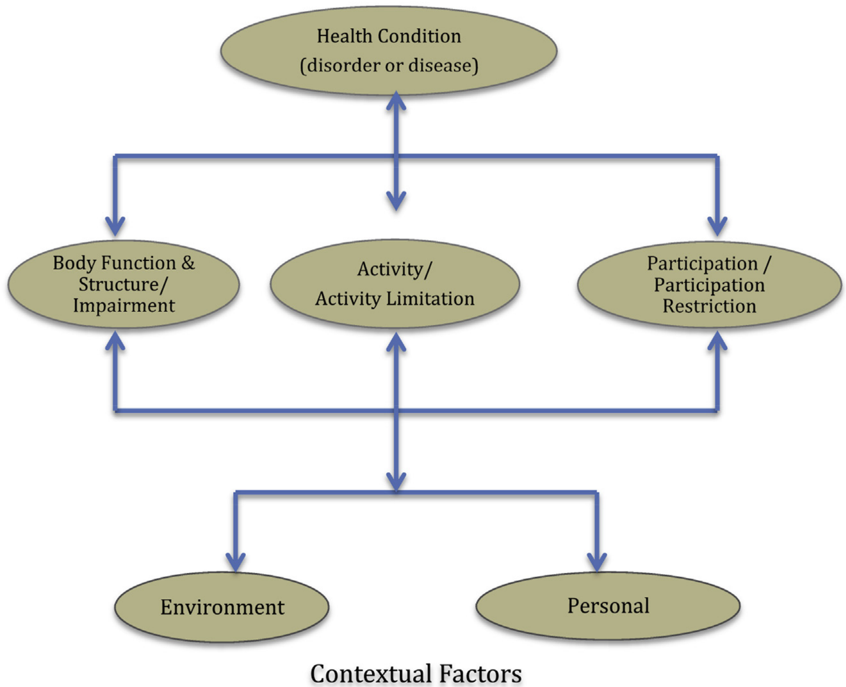

Figure 2 ICF model. International Classification of Functioning, Disability, and Health Model (ICF). Adapted from Jette, 2006.

impairment and functional findings. On an 11-point NPRS, baseline pain in her hip was 9/10 at its worst and was 0/10 at discharge. The minimum clinical important difference (MCID) is two points (Childs et al., 2005). At discharge, her low back pain was 0/10 except for occasional 3/10 upon waking in the morning that resolved within 1– 2 min of movement. The Lower Extremity Functional Scale score improved from 74/80 to 80/80 with the client below the MCID of 9 points (90% CI) (Binkley et al., 1999). The Oswestry score improved from 4/50 to a 0/50 and the reported range of MCID has been between 4 and 10.5 points with the consensus of 10 points improvement to be clinically significant (Vianin, 2008). The 15-point Global Rating of Change was rated "a great deal better" or +6 of +7, which is considered a large change (scale of small, medium and large) (Abbott and Schmitt, 2014) and the meaningful improvement is $\geq +5$ or deterioration is ≤ -5 on a 15-point scale (Kamper et al., 2009).

Discussion

The theory of neuroplasticity supports the interplay between the CNS and the musculoskeletal system. The melding together of the neurophysiological and the biomechanical approaches has been advocated for a more global systemic functional rehabilitation approach to scoliosis (Smania et al., 2008). The term "neuromusculoskeletal" more accurately describes the importance of multi-system integration and neuroplasticity within the domains of orthopedic and sports physical therapy. The *Feldenkrais* methodology used with this client demonstrates a "neuromusculoskeletal" approach.

The global transformation in the quality of movement, the resolution of pain and the improvement in functions of walking, stair climbing and running, with successful return to life activities of work and leisure, support the success of *Feldenkrais* as a viable intervention. From a *Feldenkrais* perspective, the cooperation of the whole system is essential in optimal function and movement; when any one part does more than it's share of the work, there is likely to be a breakdown, overuse and/or pain. The "spinal engine" concept proposed that combinations of two or three planes of motion combined together on the spine induce an axial torque sufficient to drive the pelvis, in contrast to the traditional model that suggested the lower extremities are the driving force for locomotion (Gracovetsky and Iacono, 1987). Initially with ambulation, this client with scoliosis exhibited very little to no spinal or pelvic movement with significant jarring through the right hip and spine. Upon discharge, her entire spine and pelvis functioned together fluidly, as demonstrated in a video of a man born without limbs who ambulates gracefully (Gracovetsky, 1998). With global integration of function of her whole system, the assumption was that learning and neuroplastic changes had taken place.

The progression of improvement with this client was much like the two steps of plasticity, as illustrated in a study of learning and skill acquisition of a five-finger exercise on the piano (Pascual-Leone et al., 2005). The first step is the unmasking of existing connections, which is a flexible, short-term modulation of existing pathways with more transient initial changes (Doidge, 2007; Pascual-Leone et al., 2005; Young and Tolentino, 2011; Bruel-Jungerman et al., 2007). The second step resulted in longer-term structural changes, although not fixed or hardwired in the

Table 3 Interventions.

Visit	Focus of *Feldenkrais*® *FI* lesson	Position	Changes following *FI*	Other treatments	Home program
1	Articulate spine for more options of spinal movement primarily in sagittal plane and to attenuate shock w/gait. Lengthening the spine to reduce curves. Importance of breath for efficient motion	Supine	Smoother gait w softer impact on R side. Less discrepancy in vertical displacement R:L w gait.	PT examination Education on caffeine intake.	*ATM*: bridging alternating with upper body articulation of spine.
2	Connect 6 cardinal directions of movement from pelvis thru the spinal column to the head for efficiency of walking, running & for shock absorption. Lengthening the spine to reduce curves. Weight shift in supine, sit and stand.	Supine Sitting Standing	Pelvic clock initially was easier L upper quadrant. All 4 quadrants became easier. Pain decreased from 6 to 4/10 during session. Not running to rest hip.	Gluteus med/max strengthening.	*ATM*: pelvic clock. PT: lateral step downs R 2 ins., L 4 ins., hip hike, side step ladder progression
3	Side bending and differentiate movement of shoulders and pelvis. Weight shift in sidelying, sit and stand. First exaggerate ease of R SB in frontal plane with a subsequent transfer of learning to SB with more ease on L. Improving R SB resulted in a release of shortened structures on R and shoulder heights became more equal.	Sidelying Sitting Standing	Ran up/down many flights of stairs for work event w/pain 1/10. Initial ease SB spine to R became easier also to L. L shoulder decreased from $2^1/_2$ inches to $^1/_2$ inch higher than R. SL stance on R steadier and skeletally stacked.		*ATM*; side bending in sidelying. PT: incrementally increase walking to 30 min over 1 week.
4	Explore rotation of spine/pelvis with arm circles related to contralateral trunk movement/arm swing in walking. Use of twist to lengthen spine. "Spinal Engine" concept for functional use of the trunk in walking.	Sidelying Walking	Arm circles easier w L arm. More length of spine noted in standing with a reduction of side bending and rotation of her scoliotic curves. New c/o lumbar pain 3/10 ↓ 2/10.	ME for pelvic obliquity and flexion and extension spinal dysfunctions.	*ATM*: arm circles in sidelying. PT: daily walks for 45 min.-focus on arm swing
5	Flexion of spine for resilience with gait. Lengthen spine from hip, LE's, UE's and head.		Walking more comfortable & fluid.	Begin light jog/shock absorption on mini tramp.	*ATM*: flexion combos-1 hand on knee, other hand behind head
6	Transmission of force through each LE for shock absorption in walking and running. Interplay between mobility, shock absorption and stability in spine and to find center/spine on foam roller. Relate breath to fluid movement. Strategies for attenuation of ground reaction forces for walking.	Supine Supine — with spine longitudinally on roller. Walking	Transmission of force through LLE, pelvis and spine is clearer than through the RLE. Pain 2 in R hip and lumbar area only w jog, not walk and didn't last after she finished jog intervals.	Intervals of walk 5 min, light jog 1 min for 30 min. Educate — new shoes, vary running surface/direction — crowned gravel roads/trails.	*ATM*: oscillating — push/pull w/feet. *ATM*/PT: rhythmic stabilization — foam roller. PT: Incrementally ↑ jog intervals/↓ walk intervals for 40 min.

7	Diagonal connection between shoulder and hip. Contralateral movement of shoulder and hip in gait. Established new options of organization over her R LE in weight bearing. "Spinal Engine" concept for functional use of the trunk in walking/running.	Supine Standing Walking	Pain 0 at the end of the visit. No pain with 40 min walk-jog intervals.	*ATM*: 4 Corner's lesson in both flexion then extension PT: ↑ intensity jog/run, ↓ walk intervals 40 min.
8	Kinesthetic awareness of organization of head/eyes related to her habitual functional movement patterns. Clarified LE/pelvis/spinal skeletal bones tactilely and various combinations of use of eyes related to spinal movements. Refine R LE weight bearing strategies. Explored ipsilateral/diagonal connections More strategies for attenuation of ground reaction forces for walking/running.	Supine Sitting Standing Walking Running	LEFS 80/80. No pain after walk/run. ODI 0/50 = 0% disability. Up/down many stairs at work for event. Balance on R leg now w/o collapse – stays skeletally stacked. Lateral step downs 8 ins. B. Ran 2 miles 0 pain ×2 the past week.	*ATM*: eye clock nod in supine Sitting – continue nod and add spinal rounding and arching PT: run 1.5 miles, walk 5 min, run 1.5 miles w/warm-up/cool-down 10 min of walking.
9	Fine tune postural sway for equilibrium w crossed leg strategy to draw attention/create novelty/"confuse" the nervous system and encourage new neural pathways to develop new habits. Optimal organization of center of gravity over the base of support for effective weight shifting over each stance LE. Organization of eyes, ears/vestibular, proprioceptive, tactile for equilibrium. Feedback/feedforward strategies.	Standing	Returned to running 3 miles/day, 4 days per week. Glut max/med gr. 5. Lateral step downs 8 ins. B. Hip hiking B 20 repetitions. Ran 2 & 3 miles with 0 pain.	*ATM*: Stand weight shift w feet parallel and w feet crossed. PT: Progress to running 4–5 miles/day, 4 days/wk.

Abbrev: *FI*: *Functional Integration*, right (R), left (L), *Awareness Through Movement* (*ATM*), physical therapy (PT), muscle energy (ME), LE LEFS ODI – see Table 1.

cortical networks, as the skills became overlearned and automatic, and the new skills were established (Doidge, 2007; Pascual-Leone et al., 2005; Bruel-Jungerman et al., 2007). Brief rest periods between variations in *FI* and *ATM* were important to freshen the client's attention to allow for learning. This may also be related to offline learning of a skill that is noted to occur after a motor skill training session or during sleep. Offline learning facilitates the progress from the fast stage of motor acquisition considered to be the functional plastic changes to the slow stage of learning resulting in CNS structural changes (Doidge, 2007; Dayan and Cohen, 2011).

In consideration of the economic pressures of visit numbers, we contemplated discharge following the seventh visit. Instead we opted to continue two more visits primarily because she had not completely met her goal of pain-free running. In retrospect, this may have provided more time for the second stage of learning and sustainability of the movement habit changes she had realized. One and two years after discharge, the client verbally reported extreme satisfaction with her continued ability to perform all activities pain-free.

Limitations

The efficacy and effectiveness of the *Feldenkrais Method* in the treatment of neuromusculoskeletal conditions such as those with scoliosis requires further research (Zarzycka et al., 2009; Hillier and Worley, 2015; Buchanan and Ulrich, 2001). There are two randomized controlled trials, with some relationship to aspects of this case, where significant improvement with *Feldenkrais ATM* was exhibited compared to the control group that received physical therapy; one study in muscle lengthening of the hamstrings without stretching (Stephens et al., 2006) and the other in a reduction in neck and shoulder complaints and disability with leisure activities (Lundblad et al., 1999). There are many studies from which we can extrapolate the theory of neuroplasticity from the neurological realm to musculoskeletal rehabilitation (Boudreau et al., 2010; Young and Tolentino, 2011; Cramer et al., 2011; Pascual-Leone et al., 2005; Tsao et al., 2010). Without assessments such as cortical mapping, it is not possible to know what cellular, chemical, or neurological changes actually occurred within this client's CNS over the course of care (Tsao et al., 2010; Pascual-Leone et al., 2005; Young and Tolentino, 2011; Boudreau et al., 2010). Even with resolution of pain, full return to functional activities, and clinically observable improvement, pre and post intervention radiographic studies would have been useful for validation of the structural improvements of the scoliotic curves and pelvic obliquity.

Rehabilitation efforts that facilitate learning and the neuroplasticity capabilities of the CNS have the greatest potential for success in the rehabilitation of neuromusculoskeletal conditions. This case and the sequelae of movement inefficiencies and musculoskeletal problems related to scoliosis and overuse demonstrate the successful application of neuroplasticity theory and the learning process through the use of the *Feldenkrais Method*.

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References

Abbott, J.H., Schmitt, J., 2014. Minimum important differences for the patient-specific functional scale, 4 region-specific outcome measures, and the numeric pain rating scale. J. Orthop. Sports Phys. Ther. 44 (8), 560–564.

Binkley, J.M., Stratford, P.W., Lott, S.A., Riddle, D.L., 1999. The lower extremity functional scale (LEFS): development, measurement properties and clinical application. Phys. Ther. 79, 371–383.

Boudreau, S.A., Farina, D., Falla, D., 2010. The role of motor learning and neuroplasticity in designing rehabilitation approaches for musculoskeletal pain disorders. Man. Ther. 15 (5), 410–414.

Bruel-Jungerman, E., Davis, S., Laroche, S., 2007. Brain plasticity mechanisms and memory: a party of four. Neuroscientist 13 (5), 492–505.

Buchanan, P.A., Ulrich, B.D., 2001. The *Feldenkrais* method: a dynamic approach to changing motor behavior. Res. Q. Exerc. Sport 72 (4), 315–323.

Childs, J.D., Piva, S.R., Fritz, J.M., 2005. Responsiveness of the numeric pain rating scale in patients with low back pain. Spine 30 (11), 1331–1334.

Cramer, S.C., Sur, M., Dobkin, B.H., et al., 2011. Harnessing neuroplasticity for clinical applications. Brain 134 (6), 1591–1609.

Daly, J.J., Ruff, R.L., 2007. Construction of efficacious gait and upper limb functional interventions based on brain plasticity evidence and model-based measures for stroke patients. Sci. World J. 7, 2031–2045.

Dayan, E., Cohen, L.G., 2011. Neuroplasticity subserving motor skill learning. Neuron 72 (3), 443–454.

Doidge, N., 2007. The Brain that Changes Itself. Penguin Books, London.

Flor, H., 2003. Cortical reorganisation and chronic pain: implications for rehabilitation. J. Rehabil. Med. 41 (Suppl.), 66–72.

Ginsburg, C., 2010. The Intelligence of Moving Bodies: a Somatic View of Life and its Consequences. AWAREing Press, Santa Fe, NM.

Gracovetsky, S.A., Iacono, S., 1987. Energy transfers in the spinal engine. J. Biomed. Eng. 9 (2), 99–114.

Gracovetsky, S.A., 1998. Non-Invasive Assessment of Spinal Function. Canada, Montreal. http://www.youtube.com/watch?v=EAMK7yR9RgI (accessed on 06.06.14.).

Hillier, S., Worley, A., 2015. The effectiveness of the feldenkrais method: a systematic review of the evidence. Hindawi Publishing Corporation Evid.-Based Complement. Altern. Med. http://dx.doi.org/10.1155/2015/752160.

Jette, A.M., 2006. Toward a common language for function, disability, and health. Phys. Ther. 86 (5), 726–734.

Kamper, S.J., Maher, C.G., Mackay, G., 2009. Global rating of change scales: a review of strengths and weaknesses and considerations for design. J. Man. Manip. Ther. 17 (3), 163–170.

Kleim, J.A., Jones, T.A., 2008. Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. J. Speech Lang. Hear. Res. 51 (1), S225–S239.

Kroenke, K., Spitzer, R.L., Williams, J.B., 2003. The patient health questionnaire-2: validity of a two-item depression screener. Med. Care 41 (11), 1284–1292.

Lundblad, I., Elert, J., Gerdle, B., 1999. Randomized controlled trial of physiotherapy and Feldenkrais interventions in female workers with neck—shoulder complaints. J. Occup. Rehabil. 9 (3), 179—194.

Negrini, S., Fusco, C., Minozzi, S., Atanasio, S., Zaina, F., Romano, M., 2008. Exercises reduce the progression rate of adolescent idiopathic scoliosis: results of a comprehensive systematic review of the literature. Disabil. Rehabil. 30 (10), 772—785.

Parent, S., Newton, P.O., Wenger, D.R., 2005. Adolescent idiopathic scoliosis: etiology, anatomy, natural history, and bracing. Instr. Course Lect. 54, 529—536.

Pascual-Leone, A., Amedi AFregni, F., Merabet, L.B., 2005. The plastic human brain cortex. Annu. Rev. Neurosci. 28, 377—401.

Schlösser, T.P., van der Heijden, G.J., Versteeg, A.L., Castelein, R.M., 2014. How 'idiopathic' is adolescent idiopathic scoliosis? A systematic review on associated abnormalities. PLoS One 9 (5), e97461, 1—10.

Smania, N., Picelli, A., Romano, M., Negrini, S., 2008. Neurophysiological basis of rehabilitation of adolescent idiopathic scoliosis. Disabil. Rehabil. 30 (10), 763—771.

Snodgrass, S.J., Heneghan, N.R., Tsao, H., Stanwell, P.T., Rivett, D.A., van Vliet, P.M., 2014. Recognising neuroplasticity in musculoskeletal rehabilitation: a basis for greater collaboration between musculoskeletal and neurological physiotherapists. Man. Ther. 19 (6), 614—617.

Stephens, J., Davidson, J., Derosa, J., Kriz, M., Saltzman, N., 2006. Lengthening the hamstring muscles without stretching using "awareness through movement". Phys. Ther. 86 (12), 1641—1650.

Tsao, H., Galea, M.P., Hodges, P.W., 2010. Driving plasticity in the motor cortex in recurrent low back pain. Eur. J. Pain 14 (8), 832—839.

Tsao, H., Hodges, P.W., 2008. Persistence of improvements in postural strategies following motor control training in people with recurrent low back pain. J. Electromyogr. Kinesiol. 18 (4), 559—567.

van Vliet, P.M., Heneghan, N.R., 2006. Motor control and the management of musculoskeletal dysfunction. Man. Ther. 11 (3), 208—213.

Vianin, M., 2008. Psychometric properties and clinical usefulness of the Oswestry disability index. J. Chiropr. Med. 7 (4), 161—163.

Weinstein, S.L., Dolan, L.A., Cheng, J.C., Danielsson, A., Morcuende, J.A., 2008. Adolescent idiopathic scoliosis. Lancet 371, 1527—1537.

Young, J.A., Tolentino, M., 2011. Neuroplasticity and its applications for rehabilitation. Am. J. Ther. 18 (1), 70—80.

Zarzycka, M., Rozek, K., Zarzycki, M., 2009. Alternative methods of conservative treatment of idiopathic scoliosis. Ortop. Traumatol. Rehabil. 11 (5), 396—412.

Zemach-Bersin, D., 2010. Foreword. In: Feldenkrais, M. (Ed.), Embodied Wisdom: the Collected Papers of Moshe Feldenkrais. Somatic Resources. San Diego and North Atlantic Books, Berkeley, pp. xi—xix.