THESIS

EFFECTS OF DECOUPLED ELLIPTICAL TRAINING ON INTERLIMB COORDINATION

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY ABBEY RAE KEENE ENTITLED EFFECTS OF DECOUPLED ELLIPTICAL TRAINING ON INTERLIMB COORDINATION BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

EFFECTS OF DECOUPLED ELLIPTICAL TRAINING ON INTERLIMB COORDINATION

During human locomotion, the spinal cord produces predictable alternating muscle activation to the lower limbs to produce functional gait. The Shifter is a novel elliptical trainer with mechanically decoupled foot pads, forcing the user to deliver precisely timed alternating foot forces to maintain cadence. A 15-20 hr training program has been developed to enhance interlimb coordination. Training consists of a demanding progression of increasingly difficult skills that require the user to move their legs independently. **PURPOSE**: To determine if the training produced neural adaptations that underlie more independent control of the leg muscles. It was hypothesized that progressed subjects (PS) would have enhanced interlimb coordination compared to control subjects (CS), as assessed by suppression of contralateral neural overflow. **METHODS**: PS (N=5) and CS (N=5) were of similar age, leg press strength, adiposity, and VO_2 max (all $P>0.05$). The subjects exerted an isometric force with the non-dominant knee extensors at 10% of maximal voluntary contraction (MVC) force under two conditions – alone (CF) or with an oscillating task by the dominant leg (OSC). For the OSC task, subjects exerted an oscillating force with the dominant knee extensors at a frequency of 0.25Hz between 0-50% of MVC, without visual feedback. Both the CF and OSC tasks were performed with (VIS) and without (NOVIS) visual force feedback of the

non-dominant target force. **RESULTS**: The force oscillations of the dominant knee extensors were performed at approximately the same frequency, average intensity, and peak force between PS and CS groups for both VIS and NOVIS. For the CS group, during VIS and NOVIS, respectively, the target matching (P=0.015, P=0.004) and control of fluctuations (P = 0.02, P=0.015) for the non-dominant leg was degraded for OSC compared with CF conditions. In contrast, the PS group showed no change in the ability of the non-dominant leg to stay on target (P=0.2) and control force fluctuations (P=0.07) during VIS. During NOVIS the PS group exhibited no change in target matching (P=0.47) and a slight increase in force fluctuations (P= 0.018) between CF and OSC. **CONCLUSIONS**: These results suggest an adaptation of the nervous system that allowed the PS subjects to reduce the effects of contralateral neural overflow. Prolonged use of the Shifter could produce enhanced interlimb control in rehabilitation, athletic, and elderly populations.

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TABLE OF CONTENTS

CHAPTER I

INTRODUCTION

Human locomotion requires that both lower limbs work together to produce coordinated gait. It is known that humans have the innate ability to generate rhythmic movement patterns (61). Central pattern generators (CPGs) located in the spinal cord control each limb separately but also communicate across to organize bipedal locomotion. CPGs work together with afferent feedback from the feet and legs and supraspinal input to help manage movement. Furthermore, different forms of locomotion require that one be able to adapt to different terrains and tasks, all the while still producing coordinated movement (45).

Numerous studies using split-belt treadmills have been performed to examine functional locomotion. The flexibility of interlimb coordination has been seen in spinal cats and human infants when given different belt speeds per leg; a disturbance to one hindlimb causes the contralateral hindlimb to respond in a functional way to maintain balance/cadence (31, 51). This illustrates the adaptability to store new patterns of interlimb coordination when the two limbs are given different tasks.

Many activities, such as walking and playing sports, require combining voluntary oscillating movement patterns. Oscillation movements are controlled by a neural

mechanism that compares the intended position of the limb and corrects for possible mismatches (30). Evidence from numerous studies consisting of limb oscillating movements suggest that sensory information from one limb drives excitatory or inhibitory flexion or extension pathways that influence the motor output of the contralateral limb (5, 6, 13, 42). Enhanced reflexes observed during alternating leg movements reflect the bilateral coordination for locomotion.

However, strong voluntary contractions directed at one muscle may irradiate, or overflow, to other muscles within the same functional group or to those in a group performing a synergistic or stabilizing role. Muscle overflow is seen in many populations; clinical patients (schizophrenia, Huntington's disease), stroke patients, children, elderly, and even healthy adults in effort induced movements (2). Being able to control muscle overflow could aid in one's balance, coordination, and reaction time. Furthermore, researching motor overflow, and things that may impact overflow, may help the understanding of motor recovery for rehabilitation, coordination, and athletic training purposes.

As stated, during locomotion the spinal cord produces predictable alternating muscle activation to the lower limbs. It has been found that sensorimotor/proprioceptive training (stabilization exercises on wobble boards, soft mats, and uneven surfaces) can enhance spinal motor control mechanisms in the elderly and restore neuromuscular function in rehabilitation patients (34). Sensorimotor training is very efficient for getting more or enhanced proprioceptive input to the neuromuscular system. Furthermore, it has been found that adaptive plasticity occurs in human muscle afferent pathways from effective conditioning, strength training, skill training, and locomotor training or

retraining (62). Adaptive plasticity occurs because the nervous system can accommodate to increases or decreases in use by changing function and control in regards to a movement pattern. Thus, training the cortical and proprioceptive pathways can help with one's balance, strength, and coordination that is lost through inactivity, aging, and injury.

A new type of training device called the "Shifter" (SHIFT: Super Heightened Instant Force Transfer) has similar sensorimotor and proprioceptive implications as mentioned above from previous studies. The Shifter is a novel decoupled elliptical trainer with mechanically decoupled foot pads, forcing the user to deliver precisely timed alternating foot forces to maintain cadence. A 15-20 hr training program consists of learning a demanding progression of increasingly difficult skills that required the user to use the legs independently has been developed and implemented. Neuromuscular responses to training on a decoupled elliptical trainer have rarely been researched.

Statement of the Purpose

1) To explore whether training on the Shifter could increase the ability of the neuromuscular system to control interlimb coordination, independently operate the legs, and to suppress contralateral activity.
2) To provide a basis for future testing to further investigate the application of the Shifter on performance, injury prevention, and rehabilitation on populations such as athletes, elderly, military, and post-stroke patients.

Hypothesis

Progressed subjects who have successfully completed the training progression on the Shifter will have enhanced interlimb coordination compared to control subjects, as assessed by suppression of contralateral neural overflow ($p < 0.05$).

CHAPTER II

LITERATURE REVIEW

Locomotion

Locomotor activities involve distinct rhythmic movement patterns. It has been known for decades that the spinal cord of humans has the inherent ability to generate coordinated rhythmic movement patterns that are produced by the activity of collections of neurons. Membrane potentials of these neurons oscillate rhythmically in the spinal cord to produce this movement and are called central pattern generators (CPGs). Further, CPGs are known as the common central core for control of human rhythmic movement and produce patterns of behavior independent of sensory input (12, 19, 35, 61). In numerous cat preparations, it has been shown that these neural oscillators lie in the lumbar spinal cord (10, 27, 31). In addition, evidence from studies of humans with spinal cord injuries and infant stepping suggests that CPGs contribute to the locomotor activity of the legs during walking, arm cycling, and in leg cycling (12, 21, 52, 60, 63). Contrary to the evidence of invertebrates and cats, there is less known about the CPGs in humans. The implications of human pattern generation are based on observations and indirect evidence.

In one of Paul Zehr's reviews (2005), he presented a model for the regulation of rhythmic human movement (61). This model states that, along with CPGs being the basic oscillation for rhythmic movement, that somatosensory (afferent) feedback and

supraspinal input help regulate movement by adjusting the level of activity from interneurons to the specific motoneuronal pools required for each task. There is a general consensus that the spinal cord can generate a detailed program without peripheral feedback or suprasegmental input (26, 61). The CPGs, however, are very sensitive to afferent feedback and descending inputs. These three work like a tripartite system in constant interaction. Furthermore, study of these interactions shows the autonomy and the interdependence of the various parts. In addition, the pattern generator is influenced by these inputs but differently according to the phases of the cyclic movement so that proper corrections can be made without disrupting the ongoing cycle of the movement (47).

Rhythmic movements have distinctively different reflex patterns from static contractions. Reflex control in human legs during rhythmic movement (cycling, running, walking) has strict dependency on the motor task performed; i.e., task-dependency (19, 50). CPGs and afferent inputs communicate in such a way that the strength of a reflex in a muscle, or a synergistic group of muscles, follows a program that is dependent on an actual task (18). A study by Dietz showed a task-dependent neuronal coupling between the arms and legs during walking but absent during standing (22). Only during walking were distinct bilateral EMG responses observed in the arm after electrical or mechanical impulses were applied to the leg.

Adaptive Locomotion

It is believed that in human locomotion, the cerebellum and other supraspinal structures play a more important role because of the additional demands of bipedal walking (41). Functional locomotion requires that limb movements be flexible enough to

accommodate different terrain, speeds, and trajectories. Furthermore, a continuous modulation of coordination within (*intralimb*) or between (*interlimb*) the legs is crucial (45). The movements of the various limbs during gait must be linked to each other to enable smooth progression and maintenance of equilibrium. Based on evidence from cat experiments, the hypothesis was formulated that for each limb there exist separate CPGs, which interact via interneuronal networks in order to provide a coupling of left and right limb movement(10, 27, 31). These separate CPGs interact with peripheral information in order to meet external demands.

Interlimb Coordination

Evidence suggests that side-specific proprioceptive information regarding the dynamics of movements is necessary to adjust the CPG locomotor activity for both legs to the actual needs for controlled locomotion (44). Many different types of functional locomotion have been studied; one of the most common is split-belt treadmill testing. The flexibility of interlimb coordination is known from split-belt locomotion in spinal cats; a disturbance to one hindlimb causes the contralateral hindlimb to respond in a functional way (31). This shows the adaptability of storing new patterns of interlimb coordination when each leg was given different treadmill speeds. Similarly, a combination of locomotor training with pharmacological and electrical stimulation improved the functional capabilities of the sensorimotor circuits that underlie locomotion in rats with complete spinal cord transection (16). The artificial stimulation, in addition to the afferent input from the limbs was sufficient to cause the CPGs to produce full weight-bearing, coordinated locomotion of the hindlimbs, in the complete absence of input from

the brain. This indicates that the spinal cord contains networks responsible for each limb which can be connected to work independently or together for functional movement (16, 24, 45).

Furthermore, many studies have been performed on how infants respond to changes in treadmill speeds because there is less of an influence from the cortical control as in adults and infant stepping is likely not yet a voluntary behavior (51, 60). The stepping behaviors of infants resemble that reported for other animals and adults under similar conditions, suggesting that the circuitry generating the alternate stepping movements is well developed at birth. A study by Thelen demonstrated that when infants were held so that each leg was on a separate treadmill belt, each of which was driven at a different speed, a shortened stance on the slow belt and an increased stance on the fast belt occurred to maintain regularly alternating steps (51). Even before voluntary locomotion both legs acted in a coordinated manner with the dynamic status of one limb affecting the behavior of the contralateral limb. The pattern generator for each limb is autonomous but interacts with its counterpart of the contralateral limb. The pattern generator for each leg has some autonomy, because different types of coupling and opposite directions of stepping are possible simultaneously in both legs. Evidence suggests that the two legs adopt different patterns of stepping, but both remain coordinated so that only one leg enters the swing phase at a time. The multiple types of coupling shown suggest that the coupling relationship among the pattern generators is very flexible (59).

Further evidence of the adaptability of interlimb coordination is seen in studying with cerebral stroke survivors (46). This implies that an impaired nervous system is

capable of the flexibility required to produce short term changes in gait symmetry and they can adjust to spatiotemporal gait parameters to changing demands. Thus, adaptive training on split-belt treadmills can be useful for rehabilitation in stroke patients.

Split-belt testing has the ability to mimic other functional situations that humans encounter in everyday life. For example, a study determined that when humans encountered an obstacle during walking (to mimic a realistic "tripping" motion), the lower limbs collaborated to increase the height of the centre of mass and provide extra time to extend the swing limb in order to overcome the obstacle and prepare for the landing (28). Postural stability, perceived threat, and step cycle all play a role to influence the locomotion response. This work demonstrated that the muscular reflex responses from a "tripping" situation during walking are critical in producing functional and ongoing locomotion (28).

Similarly, blindfolded subjects stepped over an obstacle (three runs consisting of 100 steps over the obstacle) on a treadmill while different stimuli (acoustic, nerve stimulation, and light flash) signaled an approaching obstacle (29). The aim of this study was to investigate whether a newly learned locomotor pattern can be transferred across different stimulus conditions, which is termed cross-modal transfer (CMT). In terms of stepping economy, there were improvements in performance under most of the stimuli presented while stepping over an obstacle. These improvements reflected more efficient and less energy-consuming movement. CMT was observed during gait and researchers also found that the course of motor learning depends on specific afferent information and feed-forward control. Also, the visual system plays a special role in the control of stepping movements. More CMT was seen when given full vision, as compared with an

acoustic signal or nerve stimulation. This seems logical since feed-forward information from the visual system is used in everyday life to avoid obstacles during locomotion. Thus, it can be said that training of a specific movement should be performed by using different stimulus conditions including the change to or from visual information.

In another study, electrical perturbation impulses were applied to a human limb during gait in order to examine the way in which the central nervous system generates appropriate compensatory responses (23). The limbs reacted to the impulses in a coordinated manner to maintain body equilibrium. Evidence suggests that the appropriate response pattern is in part governed by a central program generator in the spinal cord.

Furthermore, interlimb neural mechanisms that coordinate activity between muscles, specifically muscles performing antagonistic functions on opposite sides of the body, are observed in leg and arm cycling (13, 52, 63). It is suggested that during these movements, cutaneous reflexes for a particular muscle are also modulated by CPG circuits located on the same side of the spinal cord as its motor pool. Since pedaling and walking share biomechanical and neuronal control features, these mechanisms may be operational in walking as well as pedaling (52). However, results from arm cycling show a relatively weak coupling between the arms with regard to the regulation of cutaneous reflexes. Rhythmic cycling has been shown to be stronger in the legs since humans more frequently use their legs together where arms are more independently used (12).

The research discussed suggests many clinical implications. It has been shown that adaptive plasticity occurs in human muscle afferent pathways from conditioning, strength training, skill training, and locomotor training or retraining (62). The ability of the nervous system to increase or decrease activation of efferents innervating the muscle

spindle and load receptors accounts for this plasticity. This implies that rehabilitation and training can help with one's balance, strength, and coordination that is lost through inactivity, aging, and injury (7, 23, 28).

Oscillations

Voluntary movements of different limb segments are combined together into a variety of patterns during many daily activities. When two limb segments are moved together, non-mechanical constraints facilitate certain associations and impede others. The simplest mechanism for coupling oscillations of two limb segments is a common rhythm generator sending synchronous parallel commands to the muscles that move each segment (6). Oscillation movements are controlled by a neural mechanism that compares the intended position (encoded by a "central command") with the actual position (encoded by the kinesthetic feedback- muscle/tendon strain- afferents) and corrects for possible mismatches. This "position controller" provides matching of the limb position to the position intended by the central motor command, overcoming the different possible mechanical events (30).

Baldissera and Cerri performed experiments proving that cyclical voluntary movements of flexion and extension of the hand are naturally coupled with the same movements of the foot only if the extremities follow simultaneously the same direction (5, 13). On the other hand, great attention is required to move the two segments in opposite directions; a pattern which tends to reverse spontaneously to the 'easy and natural' pattern (5).

To distinguish between features of movement coupling depending on the physical characteristic of the segments, Baldissera and colleagues performed another study using cyclic coupled oscillations of the hand and foot to compare interlimb relations and phase-response of each limb. Based on the results, it is suggested that the central command that produces the foot oscillatory movements is structured as a sine-wave that is distributed to antagonist muscles in a complementary way: as long as the Tibialis Anterior motoneurones are excited, the Soleus motoneurons are inhibited, and vice versa (6).

Observations from Onushok's study suggest that contralateral hip afferent signals transmit information across the spinal cord and have the capacity to adjust reflex excitability in the ipsilateral leg (42). This finding suggests that sensory information from the leg drives excitatory or inhibitory flexion or extension pathways that influence the motor output of the contralateral leg. Also, it is suggested that in the human spinal cord an autonomous rhythm generator maintains this bilateral coordination such that alternating "out of phase" (bilateral alternating movement) motion of the legs is conserved during new stepping patterns to maintain walking stability (42, 59). Similarly, enhanced reflexes in the leg observed during alternating leg movements in this study are modulated through afferent input from the contralateral hip and reflect the bilateral coordination needed for locomotion.

On the other hand, it was evident that the pedaling of a single leg leads to inhibition of the contralateral soleus H reflex (15). Functionally, the contralateral inhibition received from the moving limb may act during movements such as walking and pedaling, to assist in ensuring that the powerful short latency autogenic reflex in soleus is not effective at inappropriate phases in the cycle of movement. Modulation of

reflex excitability in one limb during voluntary movements of another limb has been described in several recent studies (9, 13). During active pedaling with one limb, the soleus H-reflex in the contralateral resting limb undergoes a profound modulation (9). Results from a similar study involving ankle oscillations indicated that the modulation of the flexor carpi radialis H-reflex is linked to the timing of muscular activation, not related to the foot kinetics. This implies a central origin for the modulation rather than a kinesthetic origin (13).

Overflow to Contralateral Muscles

Contractions at moderate-to-high forces frequently cause unintended activity of contralateral muscles; termed contralateral or muscle overflow (49, 54). This overflow may affect other muscles within the same functional group or those in a group performing a synergistic or stabilizing role. As evidence, it has been shown that unilateral training has shown strength increases in the untrained limb (54). It is thought that the overflow involves the spreading of excitation within the central nervous system, and further that the neural mechanism triggering the contralateral activity may involve a reduction in transcallosal inhibition (3, 25, 64). It is almost impossible to isolate the effort, or excitation, to only one muscle when performing a maximal voluntary contraction of a muscle. This may be due to the simultaneous need for increased stabilizing forces, and also due to the fact that the central nervous system tends to activate groups of muscles with co-contractions rather than one individual muscle.

Many populations exhibit muscle overflow; clinical patients (Schizophrenia, Huntington's disease), stroke patients, children, elderly, and even healthy adults in effort

induced movements (2). In normal and aberrantly functioning children, motor overflow decreases with age and by age 11 it almost disappears (14). Contralateral and ipsilateral pathways may mediate childhood overflow depending on factors such as the age of the child and whether overflow is recorded from proximal or distal muscles (2).

Experiments performed by Armatas revealed that although overflow was not found in healthy young adults, it could be induced (4). In this experiment, subjects were to hold a finger force steady at 25, 50 or 75% of their maximum strength. It was found that strength does influence the intensity of overflow such that as the percentage target force increased, the level of overflow also increased. Differences in cortical activation and organization seem to mediate the intensity of overflow incidence.

Shinohara demonstrated contralateral irradiation produced in finger force tasks that were greater for the elderly than for young subjects (49). The mechanisms of overflow for the elderly were not determined but could be due to an imbalance of inhibition/facilitation of transcallosal activity, or due to reorganization and/or recruitment of cortical regions (2).

Another study related to muscle overflow examined whether motor unit synchronization increases during fatiguing contractions in the lower leg (8). Two groups performed separate experiments to induce fatigue in the knee extensor muscles: 1) nine trials of “wall-sits” at different knee angles lasting 90 seconds, and 2) 12 trials of 60 seconds of knee extensions at 10, 35, 60% MVC. Both experiments induced fatigue and resulting in an increasing inter-limb coherence (or bilateral co-activation), which reflects an increase in muscle overflow. Overflow and interlimb coherence indicate increased bilateral coupling during fatiguing contractions. The fatigue-related changes experienced

in excitability along the neural axis might facilitate the coupling of neural oscillators. Studying overflow during fatiguing conditions may provide insight into underlying mechanisms of motor organization. Furthermore, researching muscle overflow may help the understanding of cortical and motor recovery for rehabilitation purposes.

Shifter Training Implication

It has been well documented that the aging neuromuscular system is affected by various degenerative processes leading to a general slowing of neuromuscular performance (55). The question of whether a specifically designed training regimen might have an impact on structural modifications in the aging neuromuscular system has been proposed.

The impact of heavy resistance training and sensorimotor (SENSO) training in elderly men on unexpected treadmill perturbations was studied in an experiment by Granacher (34). SENSO training aims at improving sensory reception and processing, the central integration of afferent information, and the transformation of this afferent information into an adequate efferent response. The perturbations consisted of randomly decelerating the treadmill at distinct phases of the gait cycle while subjects were walking. The SENSO group trained on wobble boards, soft mats, and uneven surfaces for 13 weeks. After SENSO training, subjects were able to 1) decrease onset latency (time between the first biomechanical response and the first EMG response), 2) increase the magnitude of reflex activity following decelerating perturbation stimuli, and 3) significantly increase ankle joint stiffness during the perturbation impulses. Three adaptive mechanisms in the neuromuscular system could account for the improved ability

to compensate for treadmill perturbations due to SENSO training: 1) more efficient transmission of sensory information in the central nervous system, 2) reduction of the increased presynaptic inhibition of group-II afferents in the elderly causing an enhanced reflex activity and decrease in mean and maximum angular velocity after perturbation, and 3) enhancing the sensitivity of the muscle spindles via the gamma motor system, which increases ankle stiffness. It was found that SENSO has an impact on spinal motor control mechanisms in the elderly and these trained subjects were able to compensate for gait perturbations in a more coordinated manner. Thus, in the elderly a sufficient training stimulus has a significant impact on reflexes and therefore a functional implication for everyday walking (34).

Similarly, during rehabilitation of injuries to the locomotor system, proprioceptive training is widely accepted to restore neuromuscular functions. Proprioception is a basic information source for the control of body movements in regards to regulating balance. More specifically, proprioception describes the sensory reception of stimuli and the coding of neurological signals in combination with the afferent feedback to the central nervous system (39). Gollhofer performed a series of experiments investigating the neuromuscular adaptations following proprioceptive training interventions (postural exercises on unstable platforms, on ankle pads and on uneven surfaces; no classic strength training). There were three main results: 1) the subjects could produce maximum explosive power within shorter time periods after the training, 2) postural stabilization and overall joint stiffness were drastically reduced, which explains the improved ability of the subjects to control balance, and 3) neuromuscular responses following were enhanced in the post-training examinations (33). Enhanced afferent gains

in neuromuscular control reflect the changed ability of the neuromuscular system to activate muscles quicker and more efficiently. Thus, proprioceptive training can be an effective tool to improve intermuscular communication and could be important in rehabilitation and sport settings.

Sensory feedback training in children and on traumatic brain injured young adults prove that motor overflow can be consciously suppressed in the upper limb highlight the importance of the impact on therapeutic techniques in rehabilitation of patients, such as stroke victims who have acquired overflow. Lazarus studied boys ages 6-16 years, who were required to squeeze a pinch clip to maintain a certain force level (38). An auditory cue alerted the child to relax the passive hand if unintentional forces arose; ceasing overflow. Results showed that the children reduced the magnitude of overflow when receiving the auditory feedback. A follow-up study by Lazarus provides more evidence for the importance of mechanisms of attention on overflow production (37). Traumatic brain injured (TBI) young adults trained for three days in maintaining a percentage of their MVC, while involuntary muscle EMG activity was shown as visual feedback. Subjects reduced their overflow and were also able to maintain this reduction when tested a week later. TBI subjects could consciously control overflow and isolate motor activity; to uncouple the two limbs. This ability becomes important to understanding the mechanism of controlling overflow and also the potential for therapeutic intervention. These studies show evidence that motor overflow is plastic.

Lastly, authors from several studies conducting bilateral arm training on stroke survivors with motor impairment (using ‘bilateral arm training with rhythmic auditory cueing’ (BATRAC) a rehabilitation therapy based on the idea that bilateral movement

permits interhemispheric facilitation of the limbs (43, 58). BATRAC therapy consisted of hour long sessions three times per week for six weeks, which included pushing and pulling bilaterally handles in synchrony or alternating. Arm motor function was assessed using multiple performance tests, measuring the ability to isolate joint movements, suppress muscle overflow, and arm strength. The studies showed that repetitive bimanual training, for those with motor impairment after stroke, improved arm functioning by encouraging brain reorganization and by recruiting brain areas to provide functional benefits (40).

Thus, many populations could benefit from different types of rehabilitation training of the cortical, proprioceptive, and sensory pathways. A new type of training device called the "Shifter" has similar sensorimotor and proprioceptive implications. The Shifter is a decoupled elliptical trainer that requires the ability to control each leg independently with excellent balance, coordination, and agility. For example, one task includes reversing circular motion of one limb while keeping the other limb rotating forward with the eyes closed and hands free of support. Mastering all of the prescribed skills involves approximately 15-20 hours of practice on the machine. It seems that the neuromuscular system can be trained to improve the capability of coordinating limbs at the same time while given different tasks. Not only in rehabilitation, but to an even greater extent in athletic training, such as in alpine skiing, proprioceptive training programs may be an efficient tool to improve the agonist/antagonist intermuscular communication. It may have functional importance in all sport disciplines with explosive power demands. The Shifter could be a useful tool for improving these abilities. For this investigation we explored whether training on the Shifter could increase the ability of the

neuromuscular system to control interlimb coordination and suppress the effects of contralateral muscle contractions.

CHAPTER III

METHODS AND PROCEDURES

Subjects

Five progressed male subjects (PS) who had completed a prescribed series of skill progressions on the Shifter (age 33.0 ± 3.5 yr, height 187 ± 7 cm, body mass 88.6 ± 13.9 kg,) were compared to a group of control subjects (CS) who had never used the machine (age 30.6 ± 4.4 yr, height 182 ± 9 cm, body mass 84.1 ± 12.3 kg). The two groups reported similar athletic participation/accomplishment, current physical activity level, and no elliptical machine use for more than 30 minutes/week. Training required for Shifter subjects involved mastering a demanding progression of skills on the machine, such as reversing circular motion of one limb while keeping the other limb rotating forward with the eyes closed and hands free of support. Mastering all prescribed activities involved approximately 15-20 hours of training on the machine (Appendix C). Subjects were given a health screening form and all reported being free of diseases, medications, or injuries that could influence the dependent measures (Appendix D). Subjects were oriented to the procedures and provided informed consent (Appendix E) prior to participation. The Human Research Committee at Colorado State University approved the procedures (Appendix F) in accordance with the 1975 Helsinki Declaration.

Experimental design

Subjects participated in one 1.5 hour experiment that involved force tasks with the knee extensors: (1) Rate of Force Production (RFP), (2) maximal voluntary contraction (MVC) force, (3) constant force (CF) task with the non-dominant leg at 10% MVC, and (4) an oscillation task (OSC) during which the dominant leg performed oscillations from 0-50% MVC while the non-dominant leg maintained a constant force (10% MVC). To assess lower limb dominance, subjects were asked which leg they would use to kick a ball. The leg in which they use to kick a ball was termed their dominant leg. All subjects were right side dominant. No subjects reported being ambidextrous. No vision tests were conducted, but the subjects reported no problems in clearly viewing the computer display of visual force feedback. In addition, after the testing all subjects underwent another set of tests to measure their 1 repetition maximum (1-RM) leg press, body composition, and aerobic fitness.

Experimental procedures

Experimental Setup

Subjects were seated in a custom experimental chair with the hip joint at approximately 100° and the knee joint at 90°. The upper torso and pelvis were stabilized with straps. Load cells (LCHD-250 and LCHD-1K, 1334 N and 5337 N maximum, respectively, Omega Engineering, USA) were solidly fixed in front of the lower legs so the knee extensor force was registered through the axis of the load cell perpendicular to the shank. Load cells with different sensitivities were used to maximize the signal-to

noise ratio for the force exerted during a trial. For knee extensor measurements, the force signal was displayed on an oscilloscope for the investigator, and on a 48-cm flat panel monitor placed 75 cm in front of the subject for their viewing. For all tasks, the surface electromyogram (EMG) was measured from the vastus lateralis using 8 mm surface electrodes arranged in a bipolar fashion with a reference electrode placed over the patella (Figure1, see Appendix A for all figures and tables).

Protocol

Leg Press 1-RM

Subjects were given a three minute warm-up on a stationary bike. The subjects then lay in a supine leg press machine (2003-Leg Press, Magnum Fitness Systems, South Milwaukee, WI). The sled and foot position was adjusted so that the hip angle was flexed to 75^{o} and the knee angle was 90^{o}. The initial load was half the body mass; and single attempts were made with incrementally greater loads until failure. The right leg test preceded the left leg. Subjects were instructed to "keep the knee centered over the great toe, to straighten leg but not to lock the knee, and not use the other leg to help press." One minute of rest was given between attempts. The number of repetitions was minimized by increasing the weights to arrive at a maximal load with several attempts. The 1-RM load was recorded as the greatest load successfully lifted prior to failure at a greater load.

Body Composition

A 3-site skinfold (chest, abdomen, thigh) body composition test was given to measure percent body fat (Harpenden Skinfold Caliper CE 0120). A 3-site protocol of the chest, abdomen, and thigh on the right side of the body was used. Each site was measured three times or until two of the measurements were within 2 mm of each other. The body density and body composition formulas from the American College of Sports Medicine guidelines were used (57).

Submaximal YMCA Cycle Ergometer Test

A submaximal cycle ergometer test was used to estimate aerobic capacity. The YMCA protocol uses two to four 3-minute stages of continuous cycling to raise the steady-state heart rate (HR) of the subject to between 110 beats/min and 85% of age-predicted maximal heart rate (57). The seat was adjusted so the knee angle was at 160^{o} at the bottom of the pedal stroke with the ankle neutral (180^{o} = straight leg). Subjects wore a heart rate monitor (Polar T31). As the stages progressed, resistance was added to the ergometer according to the HR response and protocol format. To find the predicted VO_2Max, the HR measured during the last minute of the last two stages was plotted against the work rate in those stages. The line was extrapolated to estimated maximum heart rate to estimate the maximal work rate and predict the maximal oxygen consumption.

RFP task

The subject was secured in the knee extensor chair and familiarized with the protocol. For each trial, the subject was instructed to "produce the maximal amount of force as hard and as fast as you can with the testing leg and hold it for 2 s." Trials were performed until the slope of the force over the first 200ms was within 5% of each other; usually within 3–4 trials (Figure 2). At least 60 s of rest was provided between trials. The purpose was to quantify ballistic force production capability. (The lab testing protocols can be found in Appendix B).

MVC task

Force was increased from baseline to maximum over ~3 s and was held for 2-3 s with strong verbal encouragement (Figure 3). Trials were performed until the maximal force was within 5% of each other; usually within 3–4 trials (53). At least 60 s of rest was provided between trials.

Constant force matching with non-dominant leg

Subjects were instructed to increase their force to a target line (10% MVC) on the screen, and hold it on the target line as steadily as possible for 20 s (Figure 4). One practice trial with vision was performed prior to two trials with visual feedback and two trials without visual feedback. A bold horizontal line on the screen represented the target force. The muscle force was represented as a second horizontal line that moved vertically according to the force exerted. For a vision trial, the subject increased the force to the target line and was instructed to match their force with the target as steadily as possible.

For the no-vision trials, the subjects increased their force to the target line, the monitor was immediately turned off and the subjects were instructed to steadily exert the same force for 20 s. The vertical gain on the oscilloscope screen was adjusted so that the target line was always 22 cm from the bottom of the screen (in the middle of the screen). At least 30 s of rest was given between trials. The order of the vision and no-vision trials was randomized.

Simultaneous oscillations and constant force matching task

A force oscillation task (OSC) performed by the dominant leg and a constant force task (CF) performed by the non-dominant leg were completed simultaneously (Figure 5). The constant force task was performed at a target force of 10% MVC. The peak oscillation force was set at 50% MVC. A waveform generator provided a sine wave of 0.25Hz displayed on the monitor for the subject that oscillated from 0 to 50% MVC. The oscilloscope display was adjusted so that the vertical excursion of the sine wave (0-50% MVC) filled 62.5% of the screen. Subjects were instructed to "steadily track the oscillating target line by increasing and decreasing knee extension force at the same frequency as the target as best as possible." A series of ten practice oscillations were performed to accustom the subject to the oscillating frequency and force range of the task while the contralateral limb was relaxed. For a trial, the subject started by increasing their non-dominant leg to the constant force target line and holding steady at the 10% MVC target (with or without visual feedback). The dominant foot then immediately began oscillating at the same force and frequency as during the practice oscillations. Five cycles of oscillation were completed. The no-vision task was the same except that when

they increased their non-dominant leg force up to the target line, the monitor was turned off and they were told to maintain the force as steadily as possible while oscillating their dominant leg force five times. No visual feedback of the oscillating force or oscillating target was given because this was found to be overly cognitively demanding of the subjects. They were instructed to oscillate to the same force and frequency as during practice. The order of vision and no-vision trials was randomized. First, two trials of vision or no-vision were performed, then another practice round of 10 oscillations with vision were given to refresh the memory of the peak force and frequency of oscillation that was to be used. Two trials of either vision or no-vision were then performed.

Data analysis

All data were collected on-line using V-series transducer coupler or bioamplifier modules (Coulbourn Instruments, USA) and an A/D processor at 1000Hz (1401 plus, Cambridge Electronic Design, UK). Analysis was performed off-line using the Spike2 data analysis system with custom software (Cambridge Electronic Design, UK). The force signal was digitized at 1K samples/s and stored on computer using Spike2 version 5.20 software (Cambridge Electronic Design, UK). The force data was recorded raw and also hardware high-pass filtered (Butterworth 48 dB/octave, Coulbourn Instruments) at 0.5Hz to remove the slow drift in the force often present during no-vision. The EMG signal was band-pass filtered from 13-1000Hz and digitized at 2 kHz to computer. Submaximal EMG was expressed as a percentage of the maximum EMG from MVC trials (submaximal EMG/maximum EMG x 100).

Experimental measurements

The dependent variable for the RFP task was the slope of the force (% MVC/s) for the 30, 50, 100, and 200ms periods (1). For the MVC task the dependent variable was maximal force (N) from the maximal trial. The dependent variables for the CF matching tasks were mean force (N) for the original (non-detrended) force segment, standard deviation (SD, N) of force and coefficient of variation [CV = (SD/mean force) x100] of force for the detrended segment (53). The SD of force is a measure of the absolute amplitude of the force fluctuations that increases with the target force exerted (53). The CV of force is a normalized measure of force fluctuations. The EMG signal was full-wave rectified and smoothed with a 0.05s time constant. For the right leg oscillation task, the dependent variables were average time between peaks (s), average peak oscillation force (% MVC), mean force exerted (% target force), average EMG (% of maximum), average peak percent EMG of MVC.

For RFP trials, the maximum torque was measured as the force applied by knee extensor multiplied by the lever arm, which was the shank length (lateral epicondyle of the femur to the load cell contact point on the ankle). The maximum torque and the rate of force and EMG production in the first 30, 50,100, and 200 ms of the task were measured. The values were taken from the trial with the greatest rate of rise in 200ms. The rate of force or EMG rise was expressed as the percent of the maximum torque or EMG per second. The peak knee extensor force (N) during the MVC trials was taken as the MVC force. For the CF trial, the plateau portion (20s) was analyzed. Mean force (% target force), SD of filtered force, CV of filtered force, CV of EMG, and EMG (% of maximum) were measured from the CF trials. For the oscillating right leg, the average

time between peaks of the oscillation, average peak oscillation force as percent MVC, average force (% target force), average EMG (% max), and average peak EMG as percent MVC were measured. Data segments were from the start and end of the five oscillations for ~20s.

The outcome for the leg press strength was maximal load successfully lifted, or one-repetition maximum (1-RM, kg) for the left and right leg, for body composition was estimated percent fat (%), and for aerobic capacity was predicted maximal oxygen consumption (ml/kg body mass/min).

Statistical analysis

Analysis of variance (ANOVA) with repeated measures on within-subjects variables was used to first assess the overall effects. The between-subjects variable was Group (Progressed, Control) and the within-subjects variables were Oscillating Condition [constant-force (CF), oscillating (OSC)] and Visual Feedback Condition (vision, no-vision). Differences in the dependent variables between PS and CS for either leg were assessed with one-way ANOVA. For right leg force, timing, and EMG variables, paired t-tests were used to compare the vision and no-vision condition for each experimental group. Within a particular level of Visual Feedback Condition, the effect of Oscillating Condition (CF compared with OSC) on the left leg control variables was assessed with paired t-tests for each experimental group. P-values <0.05 were described as significant, but exact p-values are provided. SPSS version 16.0 was used.

CHAPTER IV

RESULTS

Subject Characteristics

Age, body mass, height, MVC force, leg press strength, percent body fat, and estimated VO_2Max were not different between the CS and PS (Table 1).

Rate of Force Production

The rate of rise in maximum torque and EMG were the key outcome variables for the rate-of-force production experiments. Overall there were no significant differences between the PS and CS in the rate of force production (% of maximum torque/sec and % of maximum EMG/s) for the 30, 50, 100, and 200ms time periods (p-values ranged from 0.41-0.98 for torque and 0.18-0.56 for EMG) (Figures 6-9). The isolated exception was a greater rate of rise in maximum vastus lateralis EMG over the 100ms time period for the CS ($p = 0.03$). There were no differences between the left and right leg for both groups for the 30, 50, 100, or 200ms time periods (p-values ranged from 0.12-0.49 for torque and 0.40-0.96 for EMG). Note: there was one extreme outlier in the PS for the values measured from the 30ms and 50ms time periods that produced larger means for the PS, but the means are not statistically significantly different.

Constant-Force and Oscillation Tasks

Right Leg OSC task

There were no significant differences between vision and no vision conditions for time between peaks (p=0.77), average peak oscillation force as percent MVC (p=0.93), mean force as percent of target force (p=0.39), EMG percent of maximum MVC (p=0.85), and average peak EMG as percent MVC (p=0.77). We therefore pooled the vision and no vision data and further analyzed data between PS and CS for the right leg OSC variables. For the pooled data, there were no significant differences between groups for the right leg OSC task for time between peaks (p=0.88), average peak oscillation force as percent target force (p=0.30), mean force as percent of target force (p=0.08), EMG percent of maximum (p=0.86), and average peak EMG as percent MVC (p=0.40) (Figures 10-14). These findings indicate that both groups performed the right leg OSC tasks similarly and had similar effects of visual conditions.

Furthermore, even when examined with visual feedback conditions, during the vision trials no differences between groups were found for all variables: time between peaks (p=0.97), average peak oscillation force as percent MVC (p=0.39), mean force as percent of target force (p=0.09), EMG percent of maximum (p=0.82), average peak EMG as percent MVC (p=0.56). Similarly, during the no vision trials no differences between groups were found for all conditions: time between peaks (p=0.68), average peak oscillation force as percent MVC (p=0.46), mean force as percent of target force (p=0.29), EMG percent of maximum (p=0.75), average peak EMG as percent MVC (p=0.65).

This data suggests that the force oscillations of the right leg were being performed at approximately the same frequency, average intensity, and average peak force between PS and CS. The average muscle activation and peak activation were also similar between groups. These are important protocol control findings because we wanted to show that the OSC task was well controlled and performed similarly between the groups. We are thus better able to compare the effects of right leg oscillation on the control of the left leg. In addition, the right leg findings proved that the task was being performed similarly between the PS and CS whether or not they had vision or no vision of the left leg task.

Left Leg Force Control

Vision and oscillation effects – both groups together

Most left leg force control variables differed between the CF and OSC task (pooled across visual feedback conditions): the mean force (% target force) decreased ($p=0.017$), the SD of filtered force increased ($p=0.001$), the CV of filtered force increased ($p=0.001$), and the SD of the EMG increased ($p=0.030$), but not the CV of the EMG ($p=0.140$). Similarly, removal of visual feedback produced significant effects for both groups.

From vision to no vision (pooled across OSC condition) the main significant findings were a trend for the mean force as percent target to decrease (97.8 ± 0.69 to 85.7 ± 2.66, $p=0.003$), the SD of force to decrease (2.52 ± 0.29 to 2.09 ± 0.29, $p=0.095$), the mean EMG as percent MVC to decrease (10.1 ± 2.08 to 8.86 ± 2.15, $p=0.028$), the CV of filtered force to decrease (3.04 ± 0.44 to 2.98 ± 0.38, $p=0.86$), and for the CV of

the EMG to decrease (17.3 ± 1.20 to 14.6 ± 1.22, p=0.08). No significant group x OSC condition or group x vision condition interactions were found

CONTROL SUBJECTS - CF vs. OSC

Visual feedback condition

For the CS, most left leg control variables were different between the CF and OSC conditions with vision. The mean force as percent target (p=0.015) decreased, and the SD (p = 0.005) and the CV of filtered force (p = 0.020) increased significantly (Figures 15-17). The CV of the EMG tended to be more variable, but the difference between CF and OSC was not significant at the 0.05 level (p=0.080). This suggests that the left leg of the CS could not stay on target, and that the force fluctuated more. Generally, there was an effect of the right leg OSC task on the left leg's performance.

No visual feedback

Similar results were found during the no vision trials for the CS. Most of the left leg control variables for the CS were different between the CF task and the OSC task. The mean force as percent target (p=0.004) decreased, and the SD of filtered force (p=0.006) and CV of filtered force (p=0.015) increased (Figures 18-20). Thus, during the no vision condition, the CS exhibited greater fluctuations in force and thus did not stay on target as well as with vision.

PROGRESSED SUBJECTS - CF vs. OSC

Visual feedback condition

In contrast to the CS, there were no differences in the left leg SD and CV of force between the CF and OSC conditions for the PS with visual feedback. The mean force as percent target (p=0.20), SD of filtered force (p=0.08), and CV of filtered force (p=0.07) were not significantly different. Also, their EMG activity showed no significant differences when going from the CF to the OSC task (CV% EMG: p=0.08 and EMG % MVC: p=0.57). This indicates that the PS remained on target and were better able to minimize the left leg variability while their right leg was performing an oscillating task (Figures 15-17).

No visual feedback

Results from the PS illustrated that only the SD and CV of the filtered force were different between the CF to the OSC task without visual feedback (p=0.05 and 0.02) (Figures 18 and 19). In addition, the PS did not significantly differ in their average mean force as a percent of the target (p=0.47) (Figure 20). As with the vision condition, the PS were better able to stay on target. The fluctuations in force increased from CF to OSC (SD filtered force: 1.05 ± 0.12 to 3.00 ± 1.46, p=0.05; CV filtered force: 1.40 ± 0.69 to 3.93 ± 1.21, p=0.02) but the fluctuations in muscle activity did not (CV% EMG: 15.2 ± 1.26 to 15.2 ± 8.45, p=0.10; EMG%MVC: 94.0 ± 2.36 to 83.6 ± 3.52, p=0.38).

Although the percent of maximum force exerted by the right leg did not differ significantly between the PS and CS, the PS exerted greater absolute forces with their right leg. The mean force was 137.4N for the CS and 202.9N for the PS. Stronger

contractions with the right leg should produce a stronger contralateral effect (25, 54, 64). Yet, even with a greater right leg force, the PS tended to control the left leg output better, which agrees with the idea that they demonstrated reduced contralateral effects.

CHAPTER V

DISCUSSION

The goal of these experiments was to determine 1) the extent to which oscillating muscle contractions on one side of the body (right knee extensors) affected the ability to control the overall force and fluctuations in force with the contralateral side (left knee extensors), and 2) the effect of training on a novel, decoupled elliptical trainer on the ability to suppress contralateral overflow of neural excitation. The experiments were designed to test the ability to produce force with the legs independently. The ability of an individual to independently control the left and right legs would be reflected in their ability to suppress the effects of the contralateral muscle contractions - here, to suppress the effects of the right leg contractions on the left leg force control.

First, we demonstrated that Control subjects (CS) and Progressed subjects (PS) performed equivalent motor tasks with the right leg, in terms of the frequency and intensity of the oscillations. Therefore, the two groups were doing the same thing with the right leg – an important experimental control. Next, we have demonstrated that the PS tended to exhibit a better ability to suppress the effects of the right leg oscillating force on the control of the left leg force. This is evidenced in both the ability to remain on a target force with the left leg and in the ability to control the fluctuations in left leg force while the right leg force was oscillating. The CS had similar athletic experience and physical fitness characteristics to the PS but had no experience with the Shifter. They exhibited less of an ability to suppress the neural overflow from the right side to the

left side, as evidenced by a generally greater effect of the right side contractions on matching of a left leg target force and controlling the variability of the left leg force. These findings were often reflected in the muscle activity as well; the PS experienced somewhat less of an effect of the right leg oscillations on the variability of the left leg EMG.

Neural Overflow

It is well known that active effort in one limb results in increased muscle activation in the non-active, contralateral muscles of the other limb (3, 8, 25, 36, 64). Our data show similar results in that the CS exhibited increased EMG in the left leg task with a different task being performed by the right leg. One possible mechanism for the increases in contralateral muscle activation is the spinal connections that are known to exist between lower limb neural networks (18). Interlimb coordination is made possible by these spinal connections, which allow information about muscle activation, interlimb reflexes, and coordination to be passed between the limbs. This has been proven in several populations, including neurologically intact subjects and individuals with spinal cord injury (20, 22, 56). Descending supraspinal drive that results in overflow and unintended muscle activation is another possible reason (5, 25). Sensory (afferent) feedback from one limb that modulates neural activity in the other limb is another possible contributor to an increase in EMG activity in the left leg (15).

Interlimb Coordination

Locomotion requires integration of sensory cues from multiple sites in the lower extremities for accurate functioning of stepping. In order for interlimb coordination to occur, afferent feedback (from limb load and proprioceptive limb input) works in

conjunction with locomotor spinal pathways (CPGs). This has been demonstrated in a study by Onushko as evidenced from contralateral hip afferent feedback having the ability to enhance or suppress reflex activity in a coordinated manner (42). Bilateral (alternating and synchronous) and unilateral hip oscillations were mechanically imposed on humans with spinal cord injury (SCI) while reflex responses in the legs were examined. Their results suggest that the ability of sensory input from a limb to modulate spinal spastic reflex activity in an organized pattern, similar to locomotion, provides evidence that hip-triggered reflex activity involves similar pathways for the spinal control of walking in human SCI. This also provides evidence for the fact that the spinal cord modulates locomotion without input from supraspinal centers. Also, previous studies show that the spinal cords in cats contain neural pathways for interlimb coordination (31, 35). Likewise, observing the stepping patterns of human infants and how they accommodate to bilateral locomotor coordination provides evidence of interlimb coordination even before independent walking (59). Similarly, our study shows the adaptability of the neural system to control interlimb coordination in different tasks as evidence by the PS being able to control their left leg while performing a task with their right leg. Presumably this is due to the adaptations produced via focused training on the Shifter and learning to control each leg more independently.

Plasticity of Neural Overflow

Evidence from several studies has demonstrated the plasticity of ability to suppress muscle overflow in many populations including young, elderly and traumatic brain-injured patients (33, 34, 37, 38). Bilateral arm training with rhythmic auditory cueing (BATRAC) in patients with motor impairment improves arm functioning

(enhanced ability to isolate movements, suppressed overflow, and increased strength) due to improved neural adaptation (40). It was observed that BATRAC training induces reorganization of contralesional motor networks and an increase in recruitment of sensorimotor areas in the brain that helps to provide functional benefits during rehabilitative training in patients with motor impairments.

Also, studies on different types of sensorimotor and proprioceptive training illustrate the adaptability of the neuromuscular system (32-34). For example, sensorimotor training in the elderly using wobble boards and uneven surfaces for exercises and performing single/bilateral balance stances proved that neural adaptations could account for the improved ability to compensate for treadmill perturbations in a more coordinated manner (34). This also illustrates the implication for enhanced functional walking in the elderly. Similarly, studies on proprioceptive training have provided evidence of improved locomotion control and demonstrate the ability to adapt to different stimuli. For example, balance training on uneven surfaces, such as tilted platforms and soft pads, produced a quicker and more efficient activation of muscles that improved intermuscular communication (32). It is known that proprioceptive training can increase and quicken the communication between the agonist and antagonist muscles to actively stabilize the joint complex to resist perturbations and to avoid ligament rupture (33). In rehabilitation and athletic settings, proprioceptive training may be an important tool to improve agonist/antagonist intermuscular communication, explosive power, isometric force development, and increase joint stiffness. In addition, another training study shows that progressive adaptations of a spinal reflex are possible in humans as a result of a daily backward walking training program (48). Subjects in this study

underwent 10 days of backward walking for 15 minutes per day and thereafter demonstrated a change in the H-reflex, the electrical analog of the stretch reflex which reflects functional characteristics of motor programming. Training led to a more normal stretch-reflex modulation pattern to allow for more functional walking. These studies are in agreement with our results as shown by the PS exhibiting a quicker and more efficient neural adaptation to new motor tasks. The PS were more capable of keeping the left leg steady at a constant force while the right leg performed oscillations. This was seen through the suppression of the contralateral muscle activity, or overflow, of the left leg as the right leg performed another task.

Mechanisms Underlying Plasticity

Possible mechanisms for the plasticity of the neural system and the ability to suppress neural overflow could include a more efficient communication of sensory information in the central nervous system by way of quicker afferent and muscle responses (34). Second, enhanced reflexes occur by a reduction of increased presynaptic inhibition of afferents, which typically occurs with old age. Having the ability to modulate the excitability of reflexes, presumably from training, can have major functional implications to locomotion, for example walking on different terrains. Third, there may be an increase in ankle joint stiffness from enhanced sensitivity of muscle spindles via the gamma motor system (34). Furthermore, the adaptations from training on the Shifter could be the result of motor learning occurring supraspinally (in the brain). Lazarus suggested that the reduction in motor overflow that results from sensory feedback training presumably involves changes in the output of supraspinal centers; more specifically the maturation of the corpus callosum (38). The function of the corpus

callosum is to transmit information from one side of the brain to the other and thus is involved in inhibiting the motor overflow of activation to the ipsilateral area (17). With increasing age, a more mature and more myelinated corpus callosum could help reduce motor overflow. Another possible adaptation from the Shifter could occur in the spinal cord and change 1) the extent to which contralateral excitation crosses over the midline of the spinal cord, or 2) reduce the effect of the crossed excitation on the neural activation of the other side (24, 45). To further demonstrate the adaptive plasticity of the spinal cord, Carrier et al. performed locomotor studies in cats with intact spinal cords and spinalized cats who were trained on a treadmill while being monitored on their locomotor performance (11). The locomotor pattern expressed after spinalization was different from the normal pattern of spinal cats, thus suggesting that some locomotor changes occurred in the spinal cord of cats. Furthermore, descending signals from supraspinal (such as the motor cortex) structures are provided to the spinal cord to compensate for the peripheral deficits. If supraspinal or spinal inhibitory mechanisms play a major role in controlling motor overflow, it is possible that the effect could be voluntarily suppressed or reduced with practice and training, such as on the Shifter.

Conclusions

The results suggest within the limits of this small-scale, cross-sectional investigation, that the decoupled elliptical training produced an adaptation at some level of the nervous system that allowed the subjects to suppress the effects of contralateral excitation. The motor skills gained during progression on the Shifter relate to the ability to suppress the alternating, rhythmic pattern of muscle activation dominant during normal human locomotion and cyclical stepping. This adaptive phenomenon in the

neuromuscular system could prove to be a useful model for studying the neural mechanisms of motor learning and adaptations of spinal cord circuits. As a preliminary step, these data suggest interesting potential adaptations of coordination that could occur with prolonged use of the Shifter - in special rehabilitation populations, athletic populations, and human aging.

Limitations, Delimitations, Assumptions

The small sample size (n=10) limits the statistical power significance of these results. However, based off of simple power tests we would find significance in some of our outcome variables with one or two more subjects. In addition, this study was cross-sectional study and not longitudinal. Our results could be confounded by cross-sectional bias, thus future examinations should include a longitudinal training study.

This study sample is delimited to males between the ages of 27 and 38 years. The control subjects did not use an elliptical training device for more than half an hour a week. Furthermore, subjects with chronic ankle problems or ankle sprains within the last six months were excluded from participating in the study.

During the initial screening, we assumed that the subjects reported correct information regarding their health, physical activity, highly skilled activity, and use of elliptical machines. Also, it was assumed that the subjects exerted maximal effort during strength tests and followed the experimental instructions as best as possible during the motor control tasks.

CHAPTER VI

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APPENDICES

APPENDIX A

Tables and Figures

TABLE 1- Subject Characteristics

	Progressed	Control	P-value
Age	33.0 ± 3.54	30.6 ± 4.39	0.37
Body Mass (kg)	88.7 ± 13.8	84.1 ± 12.3	0.60
Height(cm)	187 ± 7.01	182 ± 8.63	0.33
Left MVC(N)	954 ± 356	826 ± 167	0.49
Right MVC(N)	947 ± 346	847 ± 190	0.59
Left Leg Press 1RM (kg)	101 ± 31	109 ± 18	0.64
Right Leg Press 1RM (kg)	99.5 ± 25	108 ± 14	0.50
Percent Body Fat	11.0 ± 4.96	11.8 ± 2.21	0.74
Predicted VO_2Max (mL/kg/min)	38.8 ± 8.52	49.8 ± 13.1	0.17

Experimental Setup

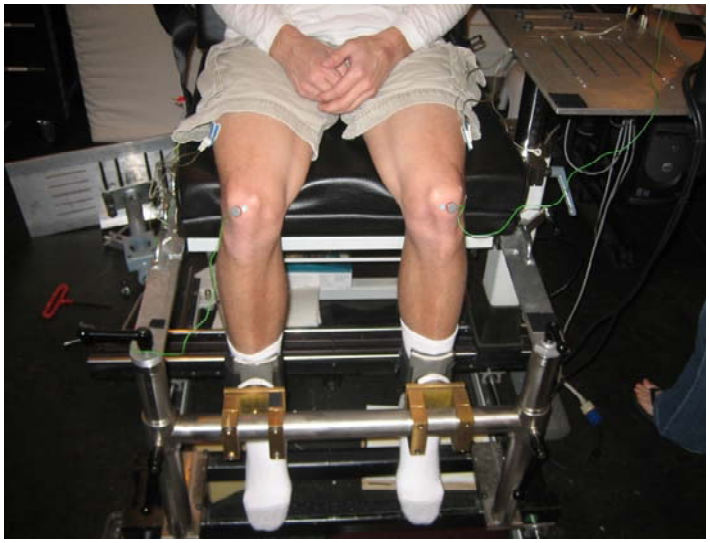

FIGURE 1: Load cells at the front of the lower legs to measure knee extensor force. Surface electrodes are placed on the vastus lateralis to measure EMG activity and on the patella for a ground.

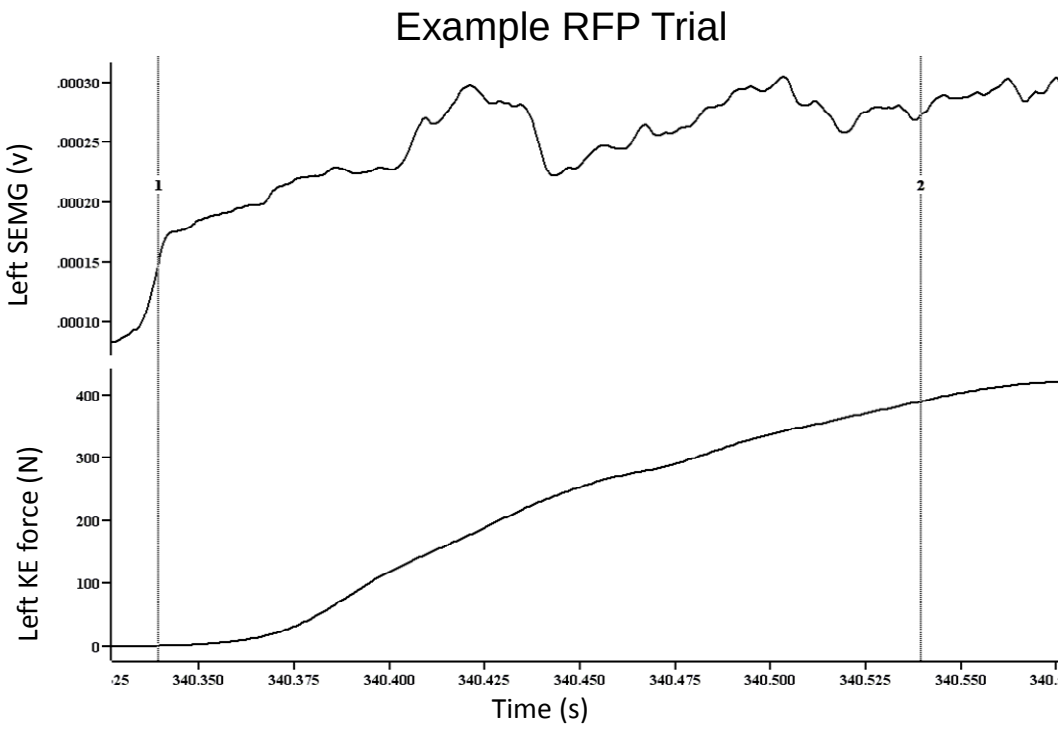

FIGURE 2: Rate of force production trial . Bottom trace: left knee extensor force, Top trace: left vastus lateralis EMG. The two vertical cursors denote the first 200ms of the trial over which the rate of rise was measured.

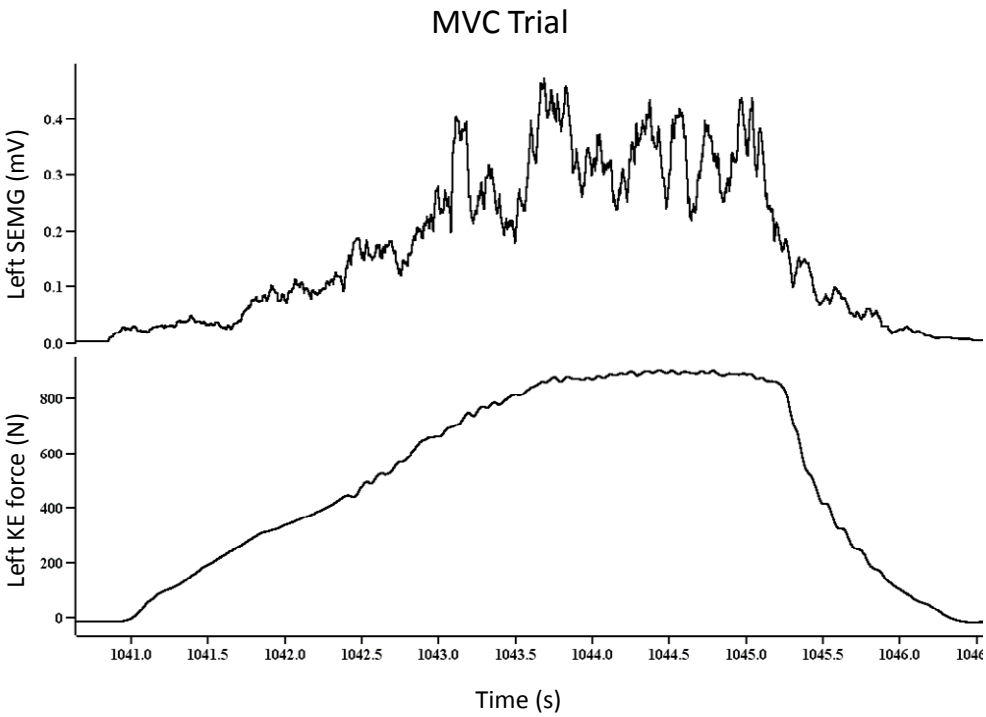

FIGURE 3: Maximum voluntary contraction trial. Bottom trace: left knee extensor force, Top trace: left vastus lateralis EMG.

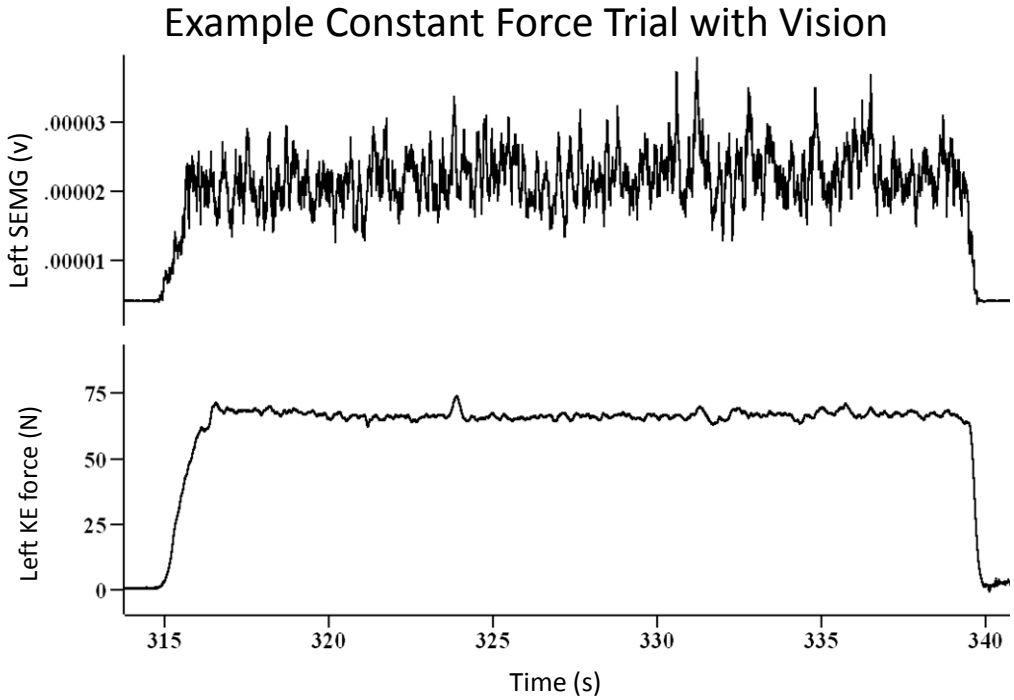

FIGURE 4: Constant force matching trial with visual feedback. Bottom trace: left knee extensor force at 10% MVC, Top trace: left vastus lateralis EMG.

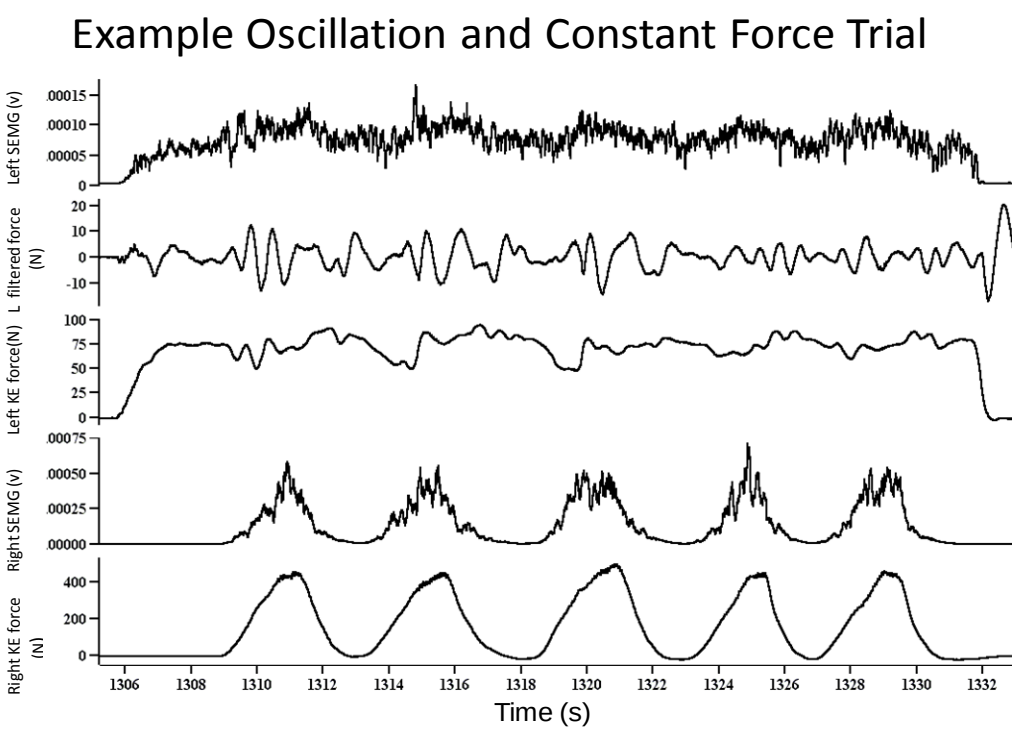

FIGURE 5: Simultaneous oscillation and constant force matching trial. Bottom to top traces: 1) right knee extensor force oscillating at 50% MVC, 2) right vastus lateralis EMG, 3) left knee extensor force at 10% MVC, 4) left knee extensor filtered force, 5) left vastus lateralis EMG.

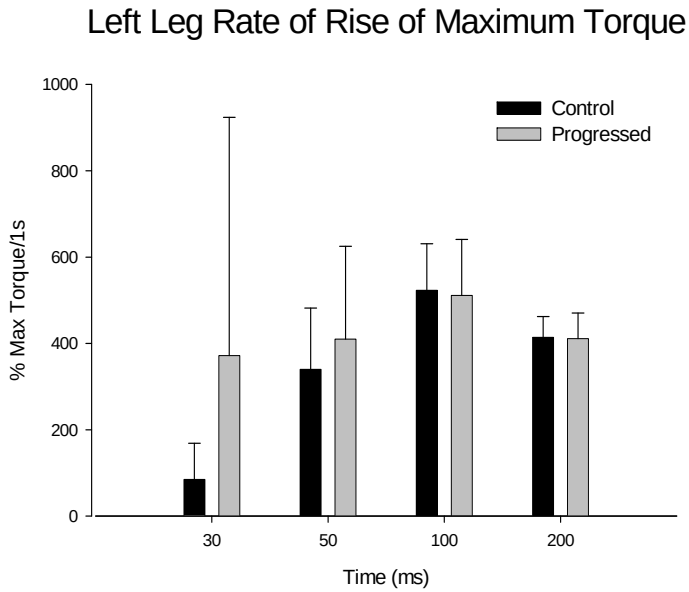

FIGURE 6: Left leg rate of rise of percent maximum torque per 1 second for Controls (CS) and Progressed (PS) at 30, 50, 100, and 200 milliseconds.

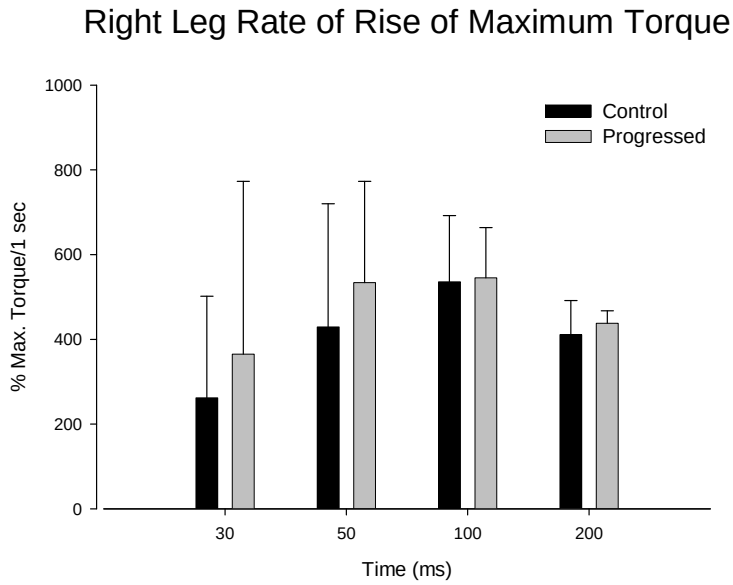

FIGURE 7: Right leg rate of rise of percent maximum torque per 1 second for CS and PS at 30, 50, 100, and 200 milliseconds.

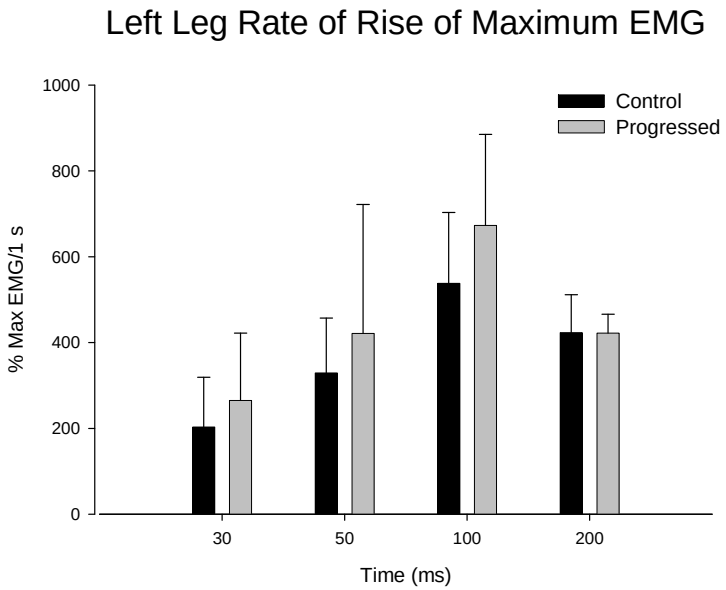

FIGURE 8: Left leg rate of rise of percent maximum EMG per 1 second for CS and PS at 30, 50, 100, and 200 milliseconds.

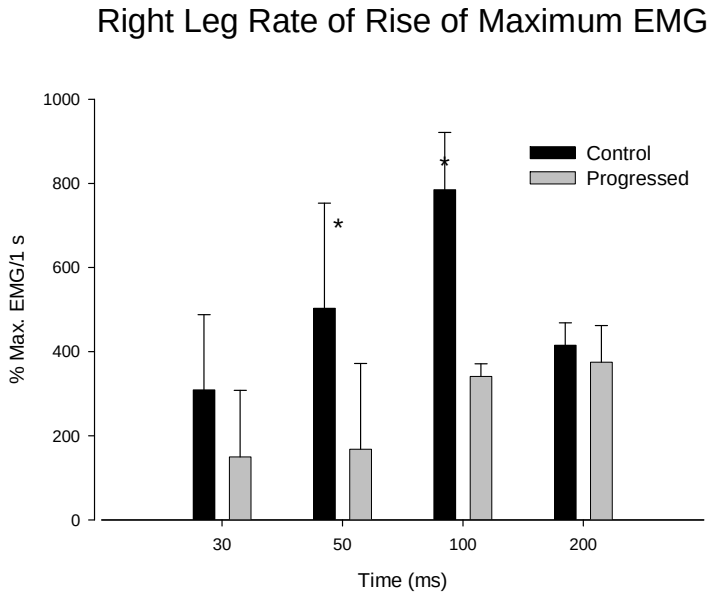

FIGURE 9: Right leg rate of rise of percent maximum EMG per 1 second For CS and PS at 30, 50, 100, and 200 milliseconds. *Significant p-value for the interaction between the groups. P=0.049 for 50ms and 0.018 for 100ms.

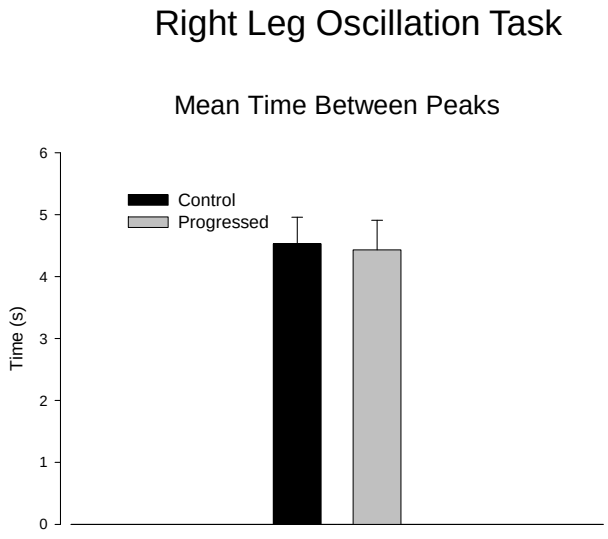

FIGURE 10: Right leg average time between peaks during the oscillation task.

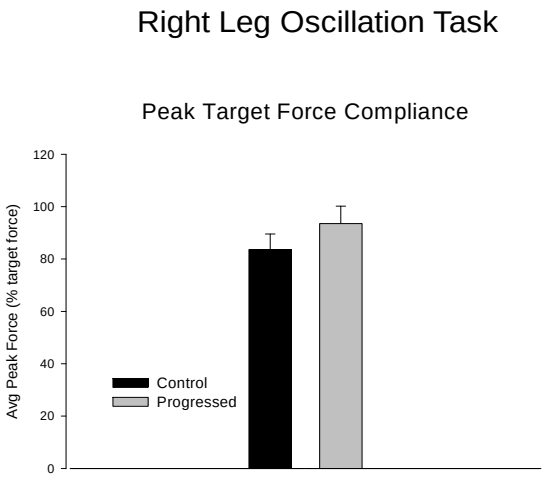

FIGURE 11: Right leg average peak oscillation force as percent target force during the oscillation task.

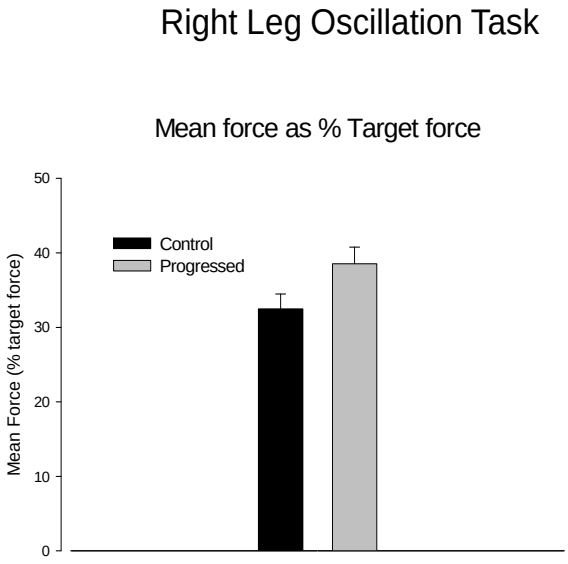

FIGURE 12: Right leg mean force as percent target force during the oscillation task.

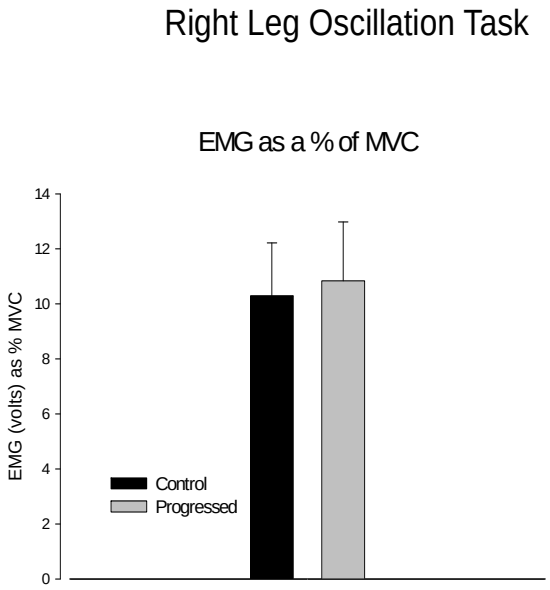

FIGURE 13: Right leg EMG as percent MVC during the oscillation task.

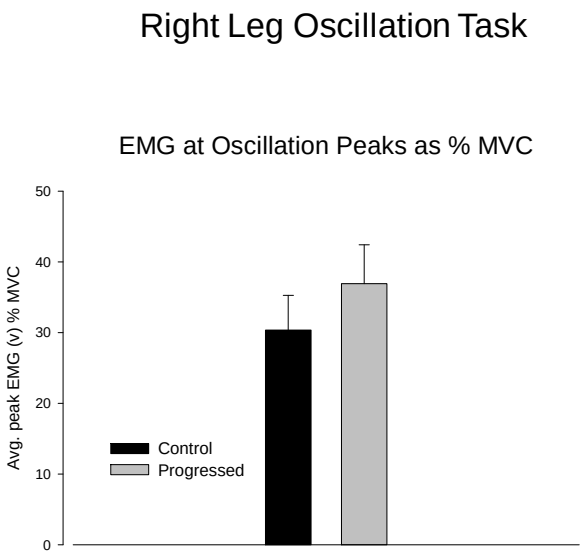

FIGURE 14: Right leg average peak EMG as percent MVC during the oscillation task.

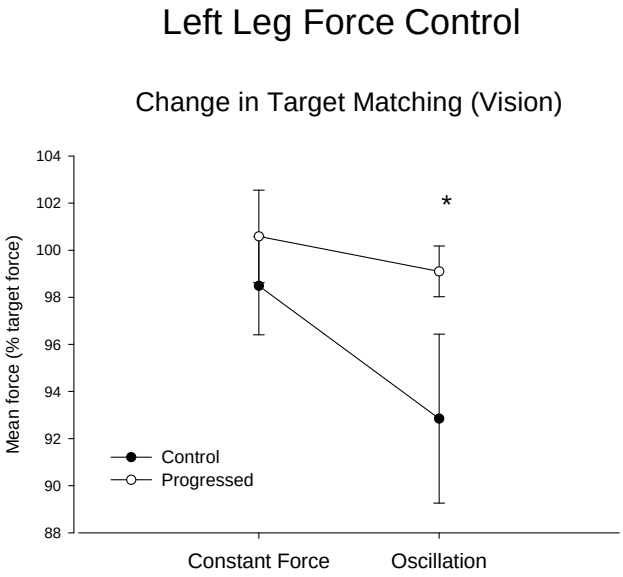

FIGURE 15: CS and PS left leg mean force as percent target force during constant force matching and oscillation trials with visual feedback. *Significant p-value=0.015 for CS and not significant p=0.2 for PS.

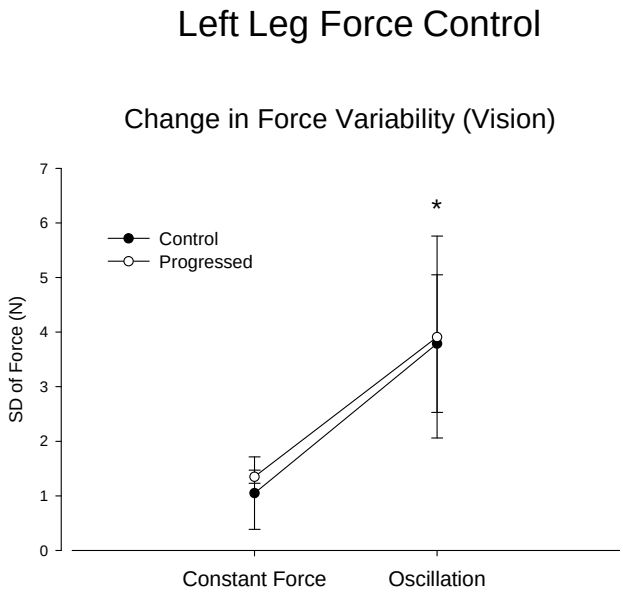

FIGURE 16: CS and PS left leg standard deviation of filtered force during constant force matching and oscillation trials with visual feedback. *Significant p-value=0.005 for CS and 0.08 for PS.

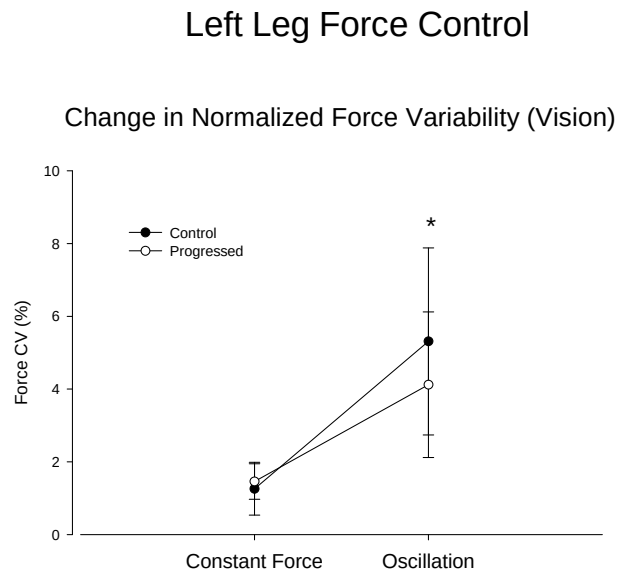

FIGURE 17: CS and PS left leg coefficient of variation of filtered force during constant force matching and oscillation trials with visual feedback. *Significant p-value=0.02 for the CS and not significant p=0.07 for the PS.

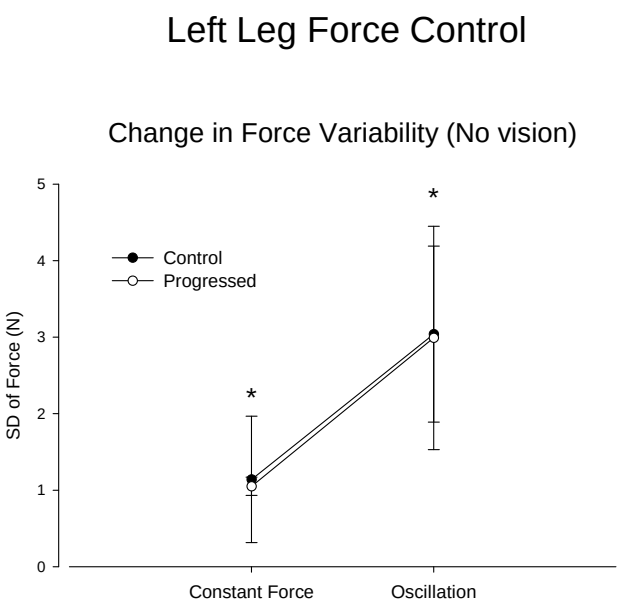

FIGURE 18: CS and PS left leg standard deviation of filtered force during constant force matching and oscillation trials without visual feedback. *Significant p-value=0.006 for the CS and 0.049 for the PS.

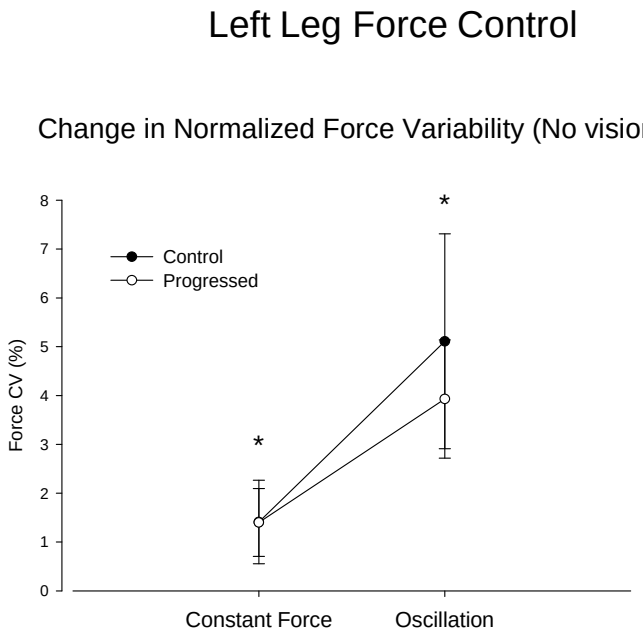

FIGURE 19: CS and PS left leg coefficient of variation of filtered force during constant force matching and oscillation trials without visual feedback. *Significant p-value=0.015 for the CS and 0.018 for the PS.

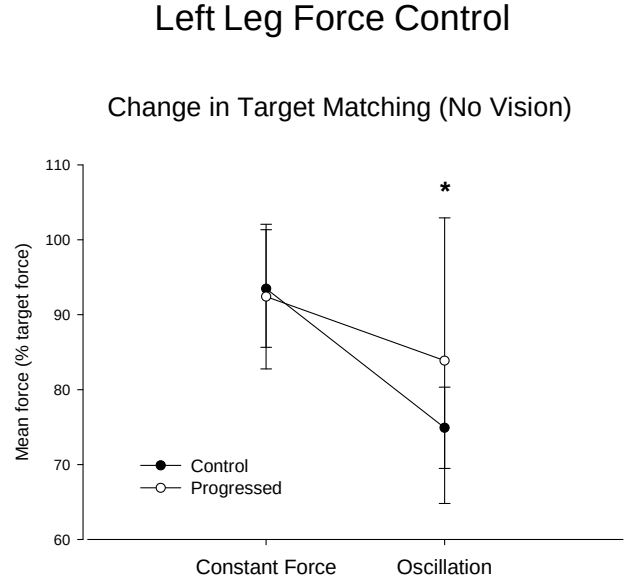

FIGURE 20: CS and PS left leg mean force as percent target force during constant force matching and oscillation trials without visual feedback. *Significant p-value=0.004 for the CS and not significant p=0.47 for the PS.

APPENDIX B

Protocol for Neuromuscular Function Lab Experiment

Subject (Code #): _____ **Initials:** _____ **Age:** _____

Date: _____

Time: _____ **Investigators:** _____

Weight_____kg **Height**_____inches Shank length:_____

Muscle Tested:_____ Dominant/kicking foot_____

1a.____KE Rate of Force Production (RFP)

Instruct subject to "produce their maximal amount of force as hard and as fast as you can with __ leg only. Hold for 2 sec." You will ask if they are ready and soon after tell them to "PUSH" as you press the space bar.
(Measure from the last baseline point to the start point of max force.)
RFP Load cell in use: # _____

Trial 1 RFP = slope =_____ N/sec _____sec

Trial 2 RFP = slope =_____ N/sec _____sec

Trial 3 RFP = slope =_____ N/sec _____sec

Trial 4 RFP = slope = _____ N/sec _____ sec

1b.____KE Rate of Force Production (RFP)

RFP Load cell in use: # _____

Trial 1 RFP = slope =_____ N/sec _____sec

Trial 2 RFP = slope =_____ N/sec _____sec

Trial 3 RFP = slope =_____ N/sec _____sec

Trial 4 RFP = slope = _____ N/sec _____ sec

2a.___ Knee Extension MVC

"We will count down from 3 to 1, and when we get to 1, you will slowly start increasing your force as we count back up to 3. Then we'll say, 'push' and you'll push as hard as you can until we say 'stop'." Show them graphic.

MVC Load cell in use: # _____ **EMG** Gain _____

Trial 1 MVC = _____ V _____ sec

Trial 2 MVC = _____ V _____ sec

Trial 3 MVC = _____ V _____ sec

Trial 4 MVC = _____ V _____ sec

Calculate MVC in Newtons: Compression Calibration Factor x V = MVC (N)
____250A Compression = 140.1 N/V _____1000A = 567.7 N/V

___KE MVC force = (cali factor ____ x Voltage ____) = _____ N

2b.___ Knee Extension MVC

MVC Load cell in use: # _____ **EMG** Gain _____

Trial 1 MVC = _____ V _____ sec

Trial 2 MVC = _____ V _____ sec

Trial 3 MVC = _____ V _____ sec

Trial 4 MVC = _____ V _____ sec

Calculate MVC in Newtons: Compression Calibration Factor x V = MVC (N)
____250B Compression = ____140.4 N/V ____1000B = ____567.3 N/V

___KE MVC force = (cali factor ____ x Voltage____) = _____ N

Save as: _ _ _ R+L RFP MVC KE.smr

3. Co-contraction Task- ____ constant KE (non-dom) with ____KE oscillation (dominant)

TAPE OVER THE TIME ON SUBJECT'S SCREEN
* Saved as "Set up 5" on scope
-Set sine wave (dominant leg) @ ~400 µsec. (straight line)
-Scope on 1 Volt setting and dial amplitude on sine box down to match scope
-Press "100" on sine box and set to 25Hz then press "1" and set to 250mHz

Make Co-contraction calculations for (___) KE:
(Non-dom) .10 x MVC (N) _____ = _____N/Cali factor _____N/V = _____V (10%) steady Target Force.
____ V/5 boxes = _____V x 1000 = _____mV (fine scale on scope)

(Dom) .50 x MVC (N) _____ = _____N / Cali factor _____N/V = _____V (50%) wave Target Force. _____V/5 boxes = _____V x 1000 = _____mV (fine scale on scope). (Set subject oscilloscope between 0 and 50% in Volts with 5 boxes.)

Co-Contract Load cell in use: # _250____ **EMG** Gain _____

-Make the sine wave visible on subject scope @ 0.25Hz, oscillating between 5 boxes from 0 and 50% (V) of subject's MVC.

1. Practice NOTES

1- Hold non-dominant leg steady for 20s. w/vision.

2- Hold non-dominant leg steady for 20s. w/no vision.

A. Control- leg steady for 20s. w/vision

"Increase your force to target line, and hold as steady as possible for 20s."

NOTES

Trial	Time
1	
2	

B. leg steady for 20s. w/novis

"Increase your force to target line. Once you are there, we will shut off the screen. We want you to hold your force as steady as possible for 20s."

NOTES

Trial	Time
1	
2	

2. Practice

3- Dominant leg oscillating 10X w/vision

C. ___ leg steady w/vis, ____ leg oscillates 5x w/novis.

"Increase your force of __ leg to target line. Start oscillating the __ leg with the same frequency and force as you did in the practice while keeping the __ leg as steady as possible on the target line. You will perform 5 oscillations."

NOTES

Trial	Time
1	
2	

3. Practice

3- Dominant leg oscillating 10X w/vision

D. ___ leg steady w/novis, ___ leg oscillates 5x w/novis.

"Again increase your force of __ leg to target line. Once you are there, we will shut off the screen. Again, you will oscillate the __ leg with the same frequency and force as you did in the practice while keeping the __ leg as steady as possible, at the same force as the previous trials. You will perform 5 oscillations."

NOTES

Trial	Time
1	
2	

Save as: _ _ _ R+L.OSC.KE.smr

NOTES, COMMENTS, ETC….

APPENDIX C

Shifter Progression

SHIFTER PROGRESSION

Source: "Spontaneous symmetrical weight shifting trainer device."
USPTO Patent Application 20060293154

1. **Phase I- General Adaptation Phase (GAP)**
    a. Client experiences motion, machine for first time.
    b. Acclimation period.
2. **Phase II- Progression Dependent Adaptation (PDA)/ Super Heightened Instant Force Transfer (SHIFT)**
    a. Progression Set 1
        i. Second stability point required (Hands on support bars)
        ii. **A. Set Up**
            1. 99% of BW on 1 footpad, so other foot ("manipulating foot") can add enough pressure to make footpad rise up to halfway point and stop here.
            2. Large amount of visual feedback required for client to transfer force off of manipulating foot right at halfway point.
        iii. **B. Set Up and Hop (Unilateral)**
            1. Rapidly hop/shift weight from one foot to the other when footpad reaches halfway point.
            2. Both feet cannot be in contact at the same time.
            3. COMPLETION: Client makes 3 hops with little movement after transfer.
        iv. **C. Pick Up**
            1. Swing both footpads at the same time, in the same direction. Pick up one foot when the footpads first reverse direction at top of swing (downswing), leaving one footpad motionless.
        v. **D. Pick Up and Hop**
            1. After Pick Up, swing through motion with contact foot, stop footpad, and hop to other foot at halfway point.
        vi. **E. No Hop, Shift, Lead Left and Lead Right**
            1. Perform Set Up (stop footpad at halfway point), but do not take all of body weight off of this foot (leave 2 ± 2% BW). Then, transfer rest of BW to other side.
            2. PURPOSE:
                a. Client gains degrees of freedom in overall skill
                b. Secondary base of support (hands) becomes less important
                c. Most of "gravity center manipulation"/weight transfer done by primary support (feet).
    b. Progression Set 2
        i. No second stability points (hands)
        ii. **Alternating Forward and Alternating Backward**

1. Allow footpads to swing all the way through motion, applying force only on the downswing.
2. COMPLETION: Client can perform task forward and backward.

iii. **Single Squash, Reverse Forward and Reverse Backward**

1. "Squash" or completely stop one footpad (1) on upswing at halfway point. Force must be transferred to other footpad (2) to continue its full rotation. As footpad 2 begins to rise, force must be transferred to footpad 1, which will swing downward in the reverse direction.
2. Maintain proper alternating cadence, with footpad 1 going backward and footpad 2 going forward, applying force only on downswings.

c. <u>Progression Set 3 (Canters and Tandems)</u>

i. **A. Canter**

1. Start with alternating cadence, determine a lead foot. Make follow foot catch up to the lead foot, so both feet will be moving in tandem.
2. Then, move from tandem back to alternating cadence.

ii. **B. Tandem**

1. Only time force is applied by both sides at the same time because client must transfer force from heel to toe at the same time on both feet.
2. Toe is weighted on the way down, heel weighted on the way up.

d. <u>Progression Set 4 (Perform Tandem Progression w/Opposing Footpad Motion)</u>

i. Pumping action is the same as 3B (Tandem), but with the feet moving in opposing directions, one going forward and one going backward.

e. <u>Progression Set 5 (Reverse User Orientation)</u>

i. Perform Sets 2 and 3, but with the client facing in the opposite direction (away from the crank/front of the machine).

f. <u>Progression Set 6 (Close Eyes)</u>

i. Perform Sets 2, 3, 4, 5 with eyes closed.

g. <u>Progression Set 7 (Add Force Vector)</u>

i. Inertia or weight resistance applied to any part of the body (arms, core, legs, etc) using weights, bands, pulleys, etc to increase force required to perform progressions.

APPENDIX D

Coded Phone Screening Form

Code number: SHIFT _____

Neuromuscular Function Lab Phone Screening - Coded Cover Sheet
(Separate from the coded screening form, store separately)

Name (Last, First): _____

Address: _____

Phone number: _____
Email: _____

Name of specific study: **_SHIFTER_**

Code number: SHIFT_____

Special Category of Subject: Shifter-_____

Initial Reason for Declining Subject: Tested: _____ - _____ am/pm

Screener's initials:_____
screening date:_____
approved: Y N_____

PHONE SCREENING – Aging, Gender, and Steadiness of Muscle Contractions
Code number:_____ Name of specific study: _____
D.O.B.:_____Age:_____Height:_____Weight:_____Sex: M F
Ethnicity:_____ Handedness:_____

Health History:
For each category, note the **extent**, **severity**, and **duration** (yrs) of condition
(Y / N)

____Arthritis: (knees, hips, hands, ankles)
Describe:_____
_____

____Neurological: (peripheral neuropathy (arm or leg numbness), Polio, Parkinson's, tremor, Alzheimers, any seizure disorders)
Describe:_____
_____

____Cancer
____Significant recent surgeries: (except for childhood tonsils, appendix, etc.)
Describe:_____
_____

____Injuries: (except for minor incidents)
Describe:_____

_____

____Metal surgical implants: (especially in the head i.e. metal plates, aneurysm clips, fusion plates)
Describe:_____
_____

____Cardiovascular Disease: (arrhythmia, heart attack, angina, heart failure, high blood pressure, stroke,
claudication)
Describe:_____
_____
____Pacemaker
____Serious vision difficulties
____Diabetes? (Type I or II)
____Steroid (cortisone) shot in the last year? _____ How many? _____ where?
____Regular smoker?
____Caffeine Intake? (ask amount and frequency)

Any other health problems?
_____
_____
_____

Medications:
List **all** medications, **condition** taken for, **dosage**, **frequency**, **length** of use._____
_____
_____

Physical Activity:
List **all** major types of physical activity participated in. Note **frequency** per week, **intensity** (mild, moderate, intense), **duration** per session, and **years** participated in.
Type:_____Frequency:_____Intensity:_____Duration:_____Years:_____
Type:_____Frequency:_____Intensity:_____Duration:_____Years:_____
Type:_____Frequency:_____Intensity:_____Duration:_____Years:_____
Type:_____Frequency:_____Intensity:_____Duration:_____Years:_____
Comments:
_____
_____

Skilled Activity:

List **any** types of activities in which you are **highly** skilled. Note **frequency** per week and **years** participated in.
Type:_____Frequency:_____ Years:_____

Type:_____Frequency:_____ Years:_____

Skilled Activity History:

List any high school or college sports you were involved in and for how long:_____
_____

Functional Ability:

Have you fallen anytime in the last year? Y/N
Describe:_____
_____

Do you ever use a cane or walker for assistance? Y/N
Can you walk up a flight of stairs without holding the rail for assistance? Y/N
Can you walk 50 feet without stopping? Y/N
Can you get into and out of a chair without using your arms for assistance? Y/N

General Questions:
Note any problems with any of the following issues:

Availability:
Treadmill test supervised by physician
Provide own transportation to CSU campus? Y/N
How did you find out about this study? _____
Would you be willing to allow us to keep your name and number on file for future studies in our lab? Y/N
Comments:_____
_____
_____

APPENDIX E

Consent Form

Consent to Participate in a Research Study
Colorado State University

TITLE OF STUDY: Effects of decoupled elliptical training on neuromuscular responses

PRINCIPAL INVESTIGATOR: *Raoul F. Reiser II, Ph.D., CSCS, FACSM 491-6958*

CO-PRINCIPAL INVESTIGATOR: *Brian L. Tracy, Ph.D., FACSM 491-2640*

WHY AM I BEING INVITED TO TAKE PART IN THIS RESEARCH? *You are a healthy individual that has completed a progression of training on the decoupled elliptical machine (as identified by its inventor/trainer, Jase Graber) or you have never trained on the machine and match closely to those in the study that have. The research is examining the differences in muscle function and leg reflexes between people who have trained on a special elliptical exercise device and those who have not performed such training.*

WHO IS DOING THE STUDY? *This research is being performed by Raoul F. Reiser II, Ph.D., and Brian L. Tracy, Ph.D., of the Department of Health & Exercise Science. Trained graduate students, undergraduate students, research associates, or research assistants are assisting with the research.*

WHAT IS THE PURPOSE OF THIS STUDY? *A "decoupled" elliptical machine has separate left and right sides compared to those that are commercially available. This difference requires the user to control the left and right sides separately. For example, when you push down on one side of the decoupled device the opposite does not automatically rise up. Training on this device may alter muscle strength, muscle control, and the speed of reflexes and reactions. The goal is to measure the effects of such training.*

WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST? *The study will take place in laboratories in the Moby Building B wing on the Colorado State University campus. Your participation will be 1-28 days in duration.*

WHAT WILL I BE ASKED TO DO? *Your participation will involve up to two testing sessions. Each testing session will last ~ 3 hours. We would like each subject to repeat the testing after a 1-4 week control period. Your willingness to participate a single time does not exclude you from the study, nor does participating in the first session commit you to the second testing session. All of the testing procedures described below will therefore be performed a total of two separate times only if you agree to have the measures repeated.*

Screening - You will be asked to answer some questions about your health and exercise habits to determine if you can participate in the study. (~ 20 minutes)
Leg press strength test - You will be asked to perform a strength test on a leg press machine. In this machine you are seated and pushing weights out with your whole leg. The test will involve

several repetitions building from light to heavy loads. The goal is to determine the most amount of weight you can press a single time. (~ 15 minutes)

Exercise bicycle test - You will participate in a test on an exercise bicycle lasting several minutes. Your heart rate will be measured periodically during the test as the resistance is gradually increased. The test will involve moderately heavy exertion but will not push you to your limits. (~ 15 minutes)

Isolated leg muscle contractions - You will sit or lie down in a special chair and perform light and heavy muscle contractions with your thigh muscles while your hips and shoulders are comfortably secured. (~ 20 minutes)

Isolated ankle muscle contractions - You will sit in a special chair and perform light and heavy muscle contractions with your ankle muscles while your leg, hips, and shoulders are comfortably secured. (~ 20 minutes)

Muscle activity measurement - Sticky electrodes will be placed on the skin over the muscles involved and will remain in place until the end of the visit. The electromyogram (EMG), or electrical activity in the muscle, will be measured with the electrodes. Natural oil in the skin will be removed with rubbing alcohol, and the skin will be gently roughened with a fine abrasive paste or cloth. (~ 5 minutes)
Electrical stimulus and response - A painful or mild electrical stimulus, lasting a fraction of a second, will be delivered to the skin of your foot with small adhesive electrodes and a standard stimulator. You will receive a total of 15 painful and 15 mild electrical stimuli. Each will be separated by several minutes. The painful stimulus feels similar to bumping your "funny bone" (back side of elbow). However, unlike bumping your funny bone there are no lingering effects. As soon as the stimulus stops, the pain also stops. It lasts just long enough to cause you to react, but no longer. The mild stimulus feels like a light tingle or tap on the skin. It is just enough so that you feel it for a fraction of a second and does not cause an immediate response.

- *The stimulus will not damage your skin.*
- *You will generally not know which foot will receive the stimulus. You will know the stimulus is coming in the next several seconds, but you will not know exactly when you will receive the stimulus.*
- *You will be asked to rapidly respond to the stimulus by moving either the stimulated leg, the other leg, or both legs.*
- *You will be standing on either a soft foam surface or a firm surface during this test.*
- *You will either have your weight on one leg, or equally on both legs when the stimulus is delivered.*
- *You will be wearing firm support devices on your ankles to prevent you from spraining your ankle. (~ 40 minutes)*

Quiet standing/balance - You will be asked to stand quietly either on one or two legs, eyes open or closed, for 30-60 seconds on a metal platform that measures forces underneath your feet. (~ 10 minutes)
Sit-to-stand – You will be asked to rise slowly from a regular chair to a standing position while your feet are on the metal platform that measures forces underneath your feet. (~ 10 minutes)
Standing jump - You will be asked to jump as high as you can with both legs with your hands on your hips. You will be standing on a metal platform that measures forces underneath your feet. (~ 10 minutes)
Body composition/bone density - The fat, muscle, and bone in your body will be measured using an x-ray device (dual-energy x-ray absorptiometer) that will scan you from head to toe while you lie quietly on a special table for approximately 15 minutes. The amount of radiation you will receive is extremely low. (~ 15 minutes)

ARE THERE REASONS WHY I SHOULD NOT TAKE PART IN THIS STUDY?

You should not take part in this study if you become pregnant, are a regular smoker, or if you develop diseases that could affect the measurements.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

Screening questionnaire – there are no known risks associated with answering health questions. All information is kept strictly confidential.

Leg press strength test - There is a slight risk of muscle strain from heavy exertion. The risk will be minimized by warming up and stretching.

Exercise bicycle test – You will feel winded during and just after the bicycle test due to the exertion required. There is a slight possibility of muscle soreness after the test, which should not last more than two days or affect your normal function. For healthy young adults, there are no significant risks associated with the bicycle test.

Isolated muscle contractions – There is a slight risk of muscle strain and muscle soreness resulting from brief strong muscle contractions. Soreness should not last more than two days or affect your normal function.

Muscle activity measurement – There is a slight risk of minor skin irritation from the skin preparation which should not last more than a day.

Electrical stimulus and response – The stimulator is designed for safe use with human participants and is isolated from dangerous electrical current. There is no risk of tissue damage or serious injury. You will be exposed to the stimulus before testing to ensure you want to proceed with the study. There is a slight risk of minor leg injury when you respond to the stimulus with a movement of the stimulated leg or other leg. There is a slight risk of falling and injury during the reaction to the stimulus. The floor around you will be padded. An assistant will serve as a spotter. Braces will be placed on your ankles to minimize the risk of ankle injury. There is a slight risk that the electrical stimulus could temporarily upset you emotionally. For example, we are aware of a similar stimulus causing a person to cry. This is not the purpose of the electrical stimulus. Procedures will be terminated if that happens.

Quiet standing/balance – There is a slight risk of loss of balance with the potential for falling and injury. This risk is extremely low because you will be closely surrounded by a handrail and a research assistant will serve as a spotter.

Standing jump - The risks associated with this test include muscle strain from exertion and leg injury or falling upon landing. These risks are slight and will be minimized by having a spotter immediately behind you during the jumps.

Body composition (DEXA) scan – The risks associated with the DEXA are very low. The radiation you will receive is less than 1/3000th of the Food and Drug Administration (FDA) limit for annual exposure. The FDA is a government organization responsible for medical safety. In other words, you could receive 3000 DEXA scans in a single year and still not meet the FDA limit for radiation exposure. In this study you will receive one scan. The more radiation you receive over the course of your life, the greater the risk of having cancerous tumors or of inducing changes in genes. The radiation in this study is not expected to greatly increase these risks, but the exact increase in such risks is not known. Women who are pregnant or could be pregnant should receive no unnecessary radiation and should not participate in this study.

It is not possible to identify all potential risks in research procedures, but the researcher(s) have taken reasonable safeguards to minimize any known and potential, but unknown, risks.

ARE THERE ANY BENEFITS FROM TAKING PART IN THIS STUDY? *The only direct benefits to you for participating in this study are the health information from the body composition assessment and a potential positive training effect from the training program. Your contribution to this study will benefit society because it will increase scientific knowledge about how the human nervous system functions.*

DO I HAVE TO TAKE PART IN THE STUDY? *Your participation in this research is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participating at any time without penalty or loss of benefits to which you are otherwise entitled.*

WHAT WILL IT COST ME TO PARTICIPATE? *There is no cost to you for participating except that associated with your transportation to our facilities.*

WHO WILL SEE THE INFORMATION THAT I GIVE? *We will keep private all research records that identify you, to the extent allowed by law. Your information will be combined with information from other people taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. You will not be identified in these written materials. We may publish the results of this study; however, we will keep your name and other identifying information private.*

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. For example, your name will be kept separate from your research records and these two things will be stored in different places under lock and key. You should know, however, that there are some circumstances in which we may have to show your information to other people. For example, the law may require us to show your information to a court, the National Institutes of Health, or to the Human Research Committee at CSU.

CAN MY TAKING PART IN THE STUDY END EARLY? *Your participation in the study could*
end in the rare event of muscle strain, if you cannot complete the testing in the prescribed manner, if you become pregnant, or if you miss an excessive number of appointments.

WILL I RECEIVE ANY COMPENSATION FOR TAKING PART IN THIS STUDY? You will receive $30 per testing visit (approximately $10 per hour).

WHAT HAPPENS IF I AM INJURED BECAUSE OF THE RESEARCH? *Please be aware that for this study the University has made special arrangements to provide initial medical coverage for any injuries that are directly related to your participation in this research project. The research project will provide for the coverage of reasonable expenses for emergency medical care related to the treatment of research-related injuries, if necessary.*

LIABILITY:

Because Colorado State University is a publicly-funded, state institution, it may have only limited legal responsibility for injuries incurred as a result of participation in this study under a Colorado law known as the Colorado Governmental Immunity Act (Colorado Revised Statutes, Section 24-10-101, et seq.). In addition, under Colorado law, you must file any claims against the University within 180 days after the date of the injury.

In light of these laws, you are encouraged to evaluate your own health and disability insurance to determine whether you are covered for any physical injuries or emotional distresses you might sustain by participating in this research, since it may be necessary for you to rely on your individual coverage for any such injuries. Some health care coverages will not cover research-related expenses. If you sustain injuries, which you believe were caused by Colorado State University or its employees, we advise you to consult an attorney.

WHAT IF I HAVE QUESTIONS? *Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions about the study, you can contact the investigators, Raoul F. Reiser, Ph.D., at (970) 491-6958, or Brian Tracy, Ph.D., at (970)491-2640, or via email at rfreiser@cahs.colostate.edu or tracybl@cahs.colostate.edu. If you would like to ask a medical doctor about your participation in the study, you may contact Russell Risma, M.D. at 491-7121. If you have any questions about your rights as a volunteer in this research, contact Janell Barker, Human Research Administrator at 970-491-1655. We will give you a copy of this consent form to take with you.*

Your signature acknowledges that you have read the information stated and willingly sign this consent form. Your signature also acknowledges that you have received, on the date signed, a copy of this document containing 5 pages.

_____ _____

Signature of person agreeing to take part in the study Date

_____

Printed name of person agreeing to take part in the study

_____ _____

Name of person providing information to participant Date

_____

Signature of Research Staff

Page 6 of 6 Participant's initials _____ Date _____

APPENDIX F

Human Subjects Approval

Colorado State University

Research Integrity & Compliance Review Office
Office of Vice President for Research
Fort Collins, CO 80523-2011
(970) 491-1553
FAX: (970) 491-2293

Notice of Approval for Human Research

Principal Investigator: Raoul Reiser, HES, 1582
Co-Principal Investigator: Brian Tracy, HES, 1582
Title: Effects of Decoupled Elliptical Training on Neuromuscular Responses

Protocol #: 08-006H **Funding Source:** n/a

Number of Participants/Records: 15 participants
Board Action: **Approval Date:** February 21, 2008 **Expires:** January 17, 2009

IRB Administrator: Janell Barker

Consent Process:
The above-referenced project was approved by the Institutional Review Board with the condition that the attached consent form is signed by the subjects and each subject is given a copy of the form. *NO changes may be made to this document without first obtaining the approval of the IRB.*

Investigator Responsibilities:

- It is the PI's responsibility to obtain this consent form from all subjects.
- It is the responsibility of the PI to immediately inform the IRB of any serious complications, unexpected risks, or injuries resulting from this research.
- It is also the PI's responsibility to notify the IRB of any changes in experimental design, participant population, consent procedures or documents. This can be done with a memo describing the changes and submitting any altered documents.
- Students serving as Co-Principal Investigators must obtain PI approval for any changes prior to submitting the proposed changes to the IRB for review and approval.
- The PI is ultimately responsible for the conduct of the project.
- A status report of this project will be required within a 12-month period from the date of review. Renewal is the PI's responsibility, but as a courtesy, a reminder will be sent approximately two months before the protocol expires. The PI will be asked to report on the numbers of subjects who have participated this year and project-to-date, problems encountered, and provide a verifying copy of the consent form or cover letter used. The necessary continuation form (H-101) is available from the RICRO web page http://ricro.research.colostate.edu.
- Upon completion of the project, an H-101 should be submitted as a close-out report.
- If approval did not accompany a proposal when it was submitted to a sponsor, it is the PI's responsibility to provide the sponsor with the approval notice.
- **Should the protocol not be renewed before expiration, all activities must cease until the protocol has been re-reviewed.**

This approval is issued under Colorado State University's OHRP Federal Wide Assurance 00000647.

Please direct any questions about the IRB's action on this project to me for routing to the IRB.

Attachment Date of Correspondence: 3/3/08