5-5-2017

The Effect of a Neuromuscular Training Program on Rate of Force Development and Knee Joint Stability in Men and Women

Jonathan Hanscom
The College at Brockport, jhanscom4@yahoo.com

The Effect of a Neuromuscular Training Program on Rate of Force Development and Knee Joint Stability in Men and Women

A Senior Honors Thesis

Submitted in Partial Fulfillment of the Requirements
for Graduation in the Honors College

By

Jonathan Hanscom

Exercise Science Major

The College at Brockport
May 5, 2017

Thesis Director: Dr. Christopher Williams, Associate Professor, KSSPE

Table of Contents

The Effect of a Neuromuscular Training Program on Rate of Force Development and Knee Joint Stability in Men and Women

Williams, C.D. & Hanscom, J.
Department of Kinesiology, Sport Studies, and Physical Education
The College at Brockport
Contact: cwilliam@brockport.edu

Abstract

Neuromuscular adaptations to resistance training account for improvement in explosive movements by increasing neural drive and efficiency, recruitment of fast twitch muscle fibers, and rate of force development. These adaptations result in the ability to generate a greater amount of muscle force over a shorter period of time, enabling a person to respond more quickly to the demands of the surrounding world. In this way, an increase in rate of force development also increases joint stability. The purpose of this study was to determine the effect of a neuromuscular training program, designed to increase rate of force development, on knee joint stability in men and women. Utilizing an Ariel Computerized Exercise System, a 4-week training program was developed. Five male and five female participants each completed the twice-a-week training program. Exercises included squats, deadlifts, lateral squats, and leg drives for three sets of ten seconds each, at 75% of maximal velocity. Pre and post-tests for knee joint stability were performed using the Landing Error Scoring System in Real Time (LESS-RT), where decreased scores indicate an increase in joint stability. Results indicated no significant differences. However, observed results yielded decreases in scores after training for both male and female participants. Female decreases in LESS-RT scores were observed to be greater than their male counterparts.

Introduction

Over 200,000 anterior cruciate ligament (ACL) injuries of the knee occur every year, many of which are accompanied by a 6-12 month rehabilitation program.[7] Reducing this number through preventative and rehabilitative training techniques designed to increase knee joint stability is one of the ways to keep athletes out of rehab and on the field.

Typically, training programs involve improving the performance of the musculature surrounding the knee, in order to provide the joint with a higher level of stability. Typically, it takes over 300 milliseconds to reach peak voluntary muscle force; however, non-contact ACL injuries occur within 70 milliseconds of striking the ground.[2, 3,6,8,24] Therefore, maximal strength training is not sufficient to meaningfully affect muscle performance that would increase the integrity of the knee during high intensity explosive movements.[4,21,23] Only the amount of force produced within 70 milliseconds is relevant; and training and rehabilitation must focus on increasing the amount of force produced during short time periods.

In order to produce more force in a shorter amount of time, an athlete must train to improve their rate of force development (RFD), which is defined as the slope of the force-time curve.[2] Increases in RFD can be attributed to an increase in force output at the onset of muscle contraction due to increased neural drive, selective recruitment of fast twitch motor units, and decreased muscle latency, all of which can be influenced through power training.[1,6,13,14, 15,16]

Optimal conditions for explosive power training adaptations allow for maximal muscular effort throughout a full range of motion.[22] Changes in the neuromuscular system are the first to appear, as adaptations occur within the central and peripheral nervous systems.[4,9,17] By training at maximal intensity and maximal speed, the central nervous system increases efferent motor outflow (neural drive).[9] As neural drive increases, neural changes develop down the corticospinal tracts, including increased synaptic activity and increased excitability.[4,9,17] These neuromuscular changes allow for more efficient recruitment of higher threshold, fast twitch muscle fibers, increasing muscle force production and decreasing contraction time.[10,11]

Typical muscle fiber recruitment follows the size principle, which reflects the body's tendency to perform work with minimal energy cost.[10] Following the size principle, low-intensity work is completed with lower threshold, slow twitch muscle fibers.[10] As work intensity increases, higher threshold, fast twitch muscle fibers are recruited at higher energy costs.[10] By requiring an athlete to train at maximal intensity and speed, the central nervous system learns to bypass the size principle, and to selectively recruit fast twitch fibers during explosive power training.[10] Early onset recruitment of high force, high speed, fast twitch muscle fibers creates a more rapid production of force.[10] Furthermore, selective neuromuscular recruitment reduces the required activation needed for subsequent recruitment of fast twitch muscle fibers, allowing these fibers to stay active throughout actions performed at a high speeds and intensities.[11]

The neuromuscular system controls dynamic movements through a complex interaction between the central nervous system (CNS), the peripheral nervous system (PNS), and the senses of the body.[15] The fastest muscle responses rely on the proprioceptive feedback system, which is critical to successful, high speed muscle control, since this information system bypasses CNS processing.[14,15] The proprioceptive feedback system is comprised of multiple reflex pathways that constantly adjust muscular activity and decrease muscle latency. Furthermore, high intensity training has shown to increase reflex potentiation by 19-53%.[3,20]

Purpose of Study

It is well documented that optimal high intensity training has been associated with increased neural drive, selective recruitment, decreased muscle latency, and increased muscular power.[1,6,13,14,15,16] Optimal training for explosive power occurs during exercises performed at maximal muscular intensity throughout a full range of motion. Under these conditions, the neuromuscular system adapts to create greater muscular force in less time, represented by increased RFD. These adaptations happen relatively quickly, and result in faster, stronger, and more powerful muscular contractions, and would be expected to increase joint stability.

Furthermore, it is well-documented that women sustain more non-contact ACL injuries than their male counterparts.[12,19] The increased frequency of non-contact ACL injuries in women has been inconclusively attributed to anatomical and hormonal differences including skeletal differences, ACL load bearing before failure, greater joint laxity, and decreased muscular stiffness.[19] Although RFD is a possible mechanism, it has not been systematically investigated.[19]

The importance of neuromuscular function on human movement is often overlooked after injury, and current practices in injury rehabilitation, that focus solely on mechanical aspects of injury, are inadequate.[4] With an increased RFD, non-contact ACL injuries – typically occurring within 70 milliseconds of striking the ground – may occur less frequently.[12] The purpose of this study was to examine the effect of a neuromuscular training program on RFD and knee joint stability in men and women. It was hypothesized that neuromuscular training would increase the stability of the knee.

Methods

Five college age males and five college age females voluntarily participated in the study (*N*=10). A college aged participant was defined as any person 18 years of age or above. Potential participants with any contraindications or lower body injuries within the past 12 months were excluded from participation. Participants had at least minimal previous lower body weight lifting experience before participating. Each participant completed a Physical Activity Readiness Questionnaire (PAR-Q), a Personal Physical Assessment and History Survey, and a Biomechanics Lab Participation Form.

Exercise Apparatus

An Ariel Computerized Exercise System (ACES) was used for training purposes. The ACES controls the speed of movement by producing hydraulic resistive force in direct response to a user's applied force throughout the entire range of motion.[10] To do so, the ACES uses a two-way feedback loop that connects its hydraulic resistance system to a computer. The computer measures the user's applied force at a frequency of 16,000 Hz and utilizes every ten data samples to adjust the flow of hydraulic fluid. By adjusting resistive force at a 1,600 Hz frequency, the resistive force is able to constantly respond to small variations in a user's force output, and movement speed is controlled throughout the range of motion. The ACES provides the following conditions.

- Movement speed is operationally defined as the lever arm's angular speed, measured in degrees per second.
- Hydraulic pressure is used to measure the user's applied force.
- Eccentric loading is minimized due to the use of a balanced lever arm, thus creating a safer training environment (body weight only during the eccentric phase).
- Through the use of pressure and position transducers, the ACES measures and records lever arm position, force application, and time.

When using the ACES, the lever arm will not move without applied force, allowing the user to stop applying force and step away at any time throughout the range of motion. With little chance of injury, the user is able to apply maximal muscle force throughout the entire range of motion for every repetition. Any changes in skeletal mechanics or fatigue are matched with the appropriate resistance to control speed.

Training

Training sessions were scheduled two times per week, for approximately 30 minutes, over a period of 4 weeks. Three, ten second sets of each of the following exercises were performed during every training session. Participants were instructed to move as fast as possible in order to complete the maximum number of repetitions.

- Squat: Typical two legged squat. Maximal knee flexion set at 90 degrees, back remains straight throughout the full range of motion.
- Deadlift: Typical two legged deadlift with a narrow stance (used to maintain participants' knee position inside the bars of the ACES). Back and arms are kept straight while the hips and the knees drive upwards.
- Lateral Squat: Single leg squat alternating sides. Leg doing the squatting steps out to the side while the other leg remains in the air. The rapid up phase of the squat moves the participant back to the starting position and toward the opposite side, where the movement is initiated again in the opposite direction by the opposite leg. Each step counts as a single rep. Back remains straight throughout the full range of motion.
- Leg Drive (Right Leg): A single leg squat performed while swinging the opposite leg. Swing leg reaches back behind the body, kept high as the hip and knee are extended. Plant leg will experience hip and knee flexion into a squatting position. The swing leg is then swung forward, pulling the knee high into the chest while the plant leg is extended to a standing position.
- Leg Drive (Left Leg): See the above description just switch the sides.

Each participant began the training program by determining absolute maximal speed attained from 3 sets of each exercise with no resistance from the ACES. During these sets, the participant was able to move the ACES lever arm as freely and as fast as possible, working against only the inertia of the lever arm. Once maximal speed was determined, each participant performed all training exercises at 75% of their maximum.

Assessment

Pre-training and post-training assessments were performed in order to measure knee joint stability using the Reliability of the Landing Error Scoring System-Real Time test (LESS-RT).[18] This test was conducted by instructing each participant to jump off a 30 cm high platform onto a force plate target. The platform was positioned at half of each participant's height away from the force plate. Specific instructions were given as follows.

- Start jump with feet shoulder width apart, toes pointed forward.
- Both feet simultaneously leave the box without a large upward motion.
- Land in the target landing area.
- Immediately rebound by jumping to maximal vertical height on landing.
- Minimize time of contact with the ground.

Before data collection began, the participants were given practice to familiarize themselves with the procedure. Once completed, three data trials were performed. Each trial was recorded using two digital cameras, one aligned with the frontal plane and another aligned with the sagittal plane. Upon completion of three jumps, the LESS-RT scoring sheet was used to determine the participant's joint stability. Joint stability scores were based on the following ten observations of the body's movements throughout the jumping, landing, and rebounding sequences (scoring range in parenthesis).

- stance width (0-1)
- maximum foot-rotation position (0-1)
- initial foot contact (0-1)
- maximum knee-valgus angle (0-2)
- amount of lateral trunk flexion (0-1)
- initial landing of feet (0-1)
- amount of knee flexion-displacement (0-2)
- amount of trunk-flexion displacement (0-2)
- total joint displacement in the sagittal plane (0-2)
- overall impression (0-2)

Scores awarded to each of the ten observations were then summed, with a lower overall score indicating greater knee joint stability.[18] Scores recorded from 3 trials were averaged.

Results

The purpose of this study was to investigate the effect of a neuromuscular training program on the knee joint stability using the LESS-RT test. Average age, weight, and height of the participants were recorded (Table 1).

Table 1
Descriptive Statistics

	Age ± SD (yrs)	Height ± SD (in)	Weight ± SD (lbs)
Men (*N*=5)	20.40 ± 1.14	68.50 ± 2.55	171.60 ± 13.24
Women (*N*=5)	24.00 ± 6.48	63.60 ± 3.85	130.00 ± 18.67

Additionally, both inter-rater and intra-rater reliability was measured. Inter-rater reliability (i.e., the degree of agreement among raters) was assessed by having a second researcher randomly re-score 10% of the total number of trials. Intra-rater reliability (i.e., the degree of agreement among repeated observations by the same rater) was assessed by having the primary investigator randomly re-score 10% of the total number of trials. Both inter-rater and intra-rater reliability resulted in statistically significant ratings which indicated reliable scoring (Table 2).

Table 2
Inter-Rater and Intra-Rater Scoring Reliability

	Correlation	*p*-Value	Significant*
Inter-Rater Reliability	0.840	0.036	Yes
Intra-Rater Reliability	1.000	0.000	Yes

*$p < .05$

Average scores of all participants were recorded for pretest jumps and posttest jumps (Table 3). A mixed-model ANOVA compared pretest and posttest scores, and did not yield significant differences ($F_{(1)}$=.511, p=.495). Although not statistically different, scores were observed to decrease from pretest (M=6.467) to posttest (M=6.200) across all participants. No statistical differences were found between females and males at the pretest ($F_{(1)}$=.148, p=.259). Statistical comparisons pre and post by gender were not significantly different ($F_{(1)}$=2.195, p=.177); however, women were observed to have lower scores than their male counterparts (Figure 1). Statistical comparisons for an interaction between gender and pre-post testing did not yield significant differences ($F_{(1)}$=.288, p=.606); however females were observed to decrease a greater relative amount from pretest to posttest (-.467, -7.8%) than their male counterparts (-.067, <-1%) (Figure 2).

Table 3
LESS RT-Score Descriptive Statistics

	Pretest	Posttest
Females		
Mean	6.067	5.600
Standard Deviation	1.06	1.48
Males		
Mean	6.867	6.800
Standard Deviation	1.02	1.26
Total		
Mean	6.467	6.200
Standard Deviation	1.07	1.44

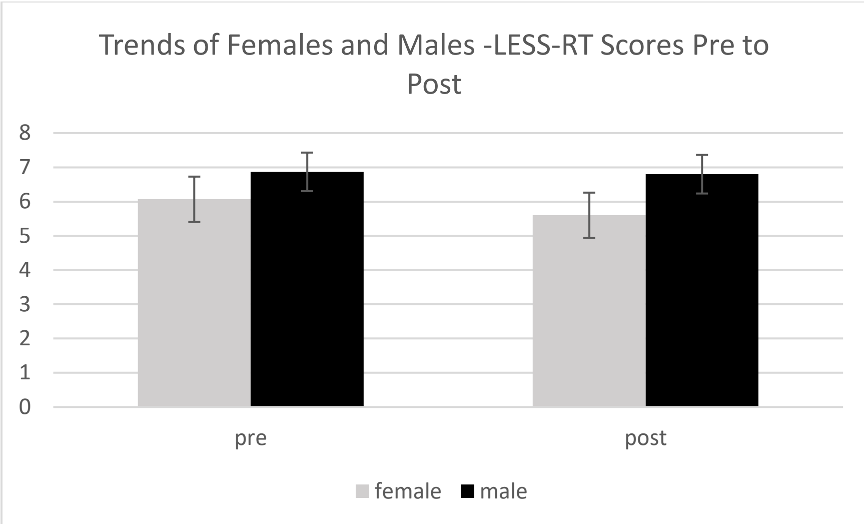

Figure 1. Pre vs. Post LESS-RT scores of males and females. Lower scores indicate improvement and greater knee joint stability.

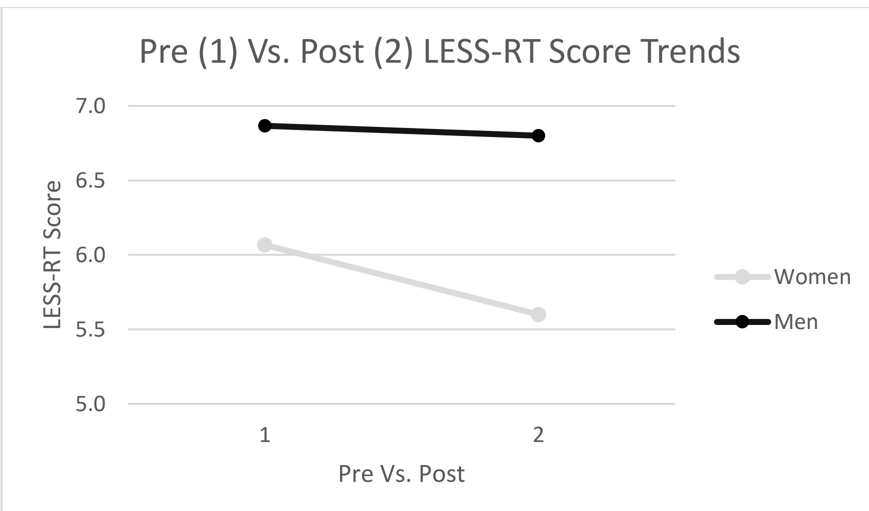

Figure 2. Pre vs. Post LESS-RT scores of males and females. Lower scores indicate improvement and greater knee joint stability.

Discussion

The purpose of this study was to investigate the effect of a 4-week neuromuscular training program designed to increase knee joint stability by improving RFD, and to determine if men and women respond differently. The LESS-RT test was used before and after training to measure knee joint stability. Although the results indicated no significant increase in knee joint stability after the neuromuscular training program, nor in how men and women responded, observed trends did follow expectations. LESS-RT scores were observed to decrease after training for both male and female participants, suggesting that joint stability was increased.

Observed trends also suggest that neuromuscular adaptations may be occurring, leading to an increase in RFD produced by the muscles surrounding the knee at the onset of contraction. Observed trends for knee joint stability increased in both men and women following completion of training. As stability increases, risk of ACL injury is reduced. Observed trends agree with the literature that has reported neuromuscular training increases RFD, and is a necessary component of ACL rehabilitation.[4]

Female scores were unexpectedly observed to be lower than male scores; and, yet, female improvements in LESS-RT scores were observed to be greater than their male counterparts. This larger improvement in women may be indicative of a greater improvement in RFD as a result of training, and suggests that women in particular may benefit from a longer duration power training program.

Lower female scores than expected could possibly be explained by the methods used by the LESS-RT test to assess knee joint stability. The LESS-RT test analyzes ten different aspects of the landing and jump. By doing so, it de-emphasizes certain aspects of the landing, such as knee valgus, which is known to effect the stability of the knee in women. A different test may have been more conducive to directly evaluate knee joint stability with regard to ACL injury.

Future Directions

A lack of significance was likely influenced by a small sample size. However, since observed trends were as hypothesized, continuation of this study to collect a bigger sample is supported.

In this study, a neuromuscular training program was observed to cause trends suggesting an increase in joint stability although no statistically significant differences were found. In order to maximize potential benefits from training, it will be important to compare training strategies used to improve RFD, neuromuscular function, and joint stability (e.g., ACES, free weights, machines, bands), and to measure RFD directly. However, it is quite difficult to measure RFD in a valid and reliable way, especially during high speed movements, thus creating a barrier for widespread investigation. [22]

Furthermore, neuromuscular training program design variables can be manipulated. Program design variables include length of training program, exercise selection, exercise order, training frequency, and training intensity, among others. Manipulation of program design variables will further identify optimal neuromuscular training for increased RFD and joint stability.

Conclusion

The purpose of this study was to examine the effect of a neuromuscular training program on RFD and knee joint stability in men and women. It was hypothesized that neuromuscular training would increase the stability of the knee. The results indicated no significant increase in knee joint stability after completing the neuromuscular training program. However, observed results did support expectations, since joint stability was observed to improve after training for both male and female participants.

References

1. Aagaard, P. (2003). Training-induced changes in neural function. *Exercise and Sports Science Review*, *31*, 61-67.

2. Aagaard, P., Simonsen, E.G., Anderson, J.L, Magnusson, P., & Dyhre-Poulsen, P. (2002). Increased rate of force development and neural drive of human skeletal muscle following resistance training. *Journal of Applied Physiology*, *93*(4), 1318-1326. DOI: 10.1152/japplphysiol.00283.2002

3. American College of Sports Medicine. Draemer, W.J. Writing Group Chairman. Position Stand: Progression models in resistance training for healthy adults. *Medicine and Science in Sport and Exercise*, *34*, 364-380.

4. Angelozzi, M., Madama, M., Corsica, C., Vittorio, C., Gianfrancon, P., McCaw, S.T., et al. (2012). Rate of force development as an adjunctive outcome measure for return-to-sport decisions after anterior cruciate ligament reconstruction. *Journal of Orthopedic and Sports Physical Therapy*, *42*(9), 772-780.

5. Ariel, G. (2012). ACES Features. http://www.arielnet.com/aces/features

6. Baechle, T.R., & Earle, R.W. (2000). *Essentials of Strength Training and Conditioning, 3rd Edition*. Champagne, IL: Human Kinetics.

7. Department of Orthopedic Surgery. (n.d.). Anterior Cruciate Ligament Injury (ACL). http://orthosurg.ucsf.edu/patient-care/divisions/sports-medicine/conditions/knee/anterior-cruciate-ligament-injury-acl/

8. Deschenes, M.R., Covault, J., Kraemer, W.J., & Maresh, C.M. (1994). The neuromuscular junction: Muscle fiber type differences, plasticity, and adaptability to increased and decreased activity. *Sports Medicine*, *17,* 358-372.

9. Dettmers, C., Ridding, M.C., Stephan, R.M., Lemon, J.C., Rothwell, R.S., & Frackowiak, R.S. (1996). Comparison of regional cerebral block flow with transcranial magnetic stimulation at different forces. *Journal of Applied Physiology*, *81*, 596-603.

10. Fleck, S.J., & Kraemer, W.J. (2003). *Designing Resistance Training Programs, 3rd ed*. Champagne, IL: Human Kinetics.

11. Gorassini, M., Yang, J.F., Siu, M., & Bennett, D.J. (2002). Intrinsic activation of human motor units: Reduction of motor unit recruitment thresholds by repeated contractions. *Journal of Neurophysiology*, *87,* 1859-1866.

12. Hewett, T.E., Lindenfeld, T.N., Riccobene, J.V., & Noyes, F.R. (1999). The effect of neuromuscular training on the incidence of knee injury in female athletes. *The American Journal of Sports Medicine*, *27*(6), 699-706.

13. Kawamori, N., & Haff, G.G. (2004). The optimal training load for the development of muscular power. *Journal of Strength and Conditioning Research*, *18*(3), 675-684.

14. Lephart, S., Swanik, C.B., Fu, F., & Huxel, K. (2011). Re-establishing neuromuscular control. In Prentice, W.E. (Ed.), *Rehabilitation Techniques for Sport Medicine and Athletic Training*, 122-138. New York: McGraw-Hill.

15. Marieb, E.N., & Hoehn, K. (2012). *Human Anatomy & Physiology, 9th ed*. San Francisco: Pearson.

16. Newton, R.U., & Kraemer, W.J. (1994). Developing explosive muscular power: Implications for a mixed methods training strategy. *Strength and Conditioning Journal*, *16*(5), 20-31.

17. Newton, R.U., Kraemer, W.J., Häkkinen, K., Humphries, B.J., & Murphy, A.J. (1996). Kinematics, kinetics and muscle activation during explosive upper body movements: Implications for power development. *Journal of Applied Biomechanics*, *12*, 31-43.

18. Pauda, D.A., Bvoling, M.C., DiStefano, L.J., Onate, J. A., Beutler, A.I., & Marshall, S.W. (2011). Reliability of the landing error scoring system-real time, a clinical assessment tool of jump-landing biomechanics. *Journal of Sport Rehabilitation*, *20*, 145-156.

19. Renstrom, P., Ljungqvist, A., Arendt, E., Beynnon, B., Fukubayashi, T., Garrett, W., et al. (2008). Non-contact ACL injuries in female athletes: An international Olympic Committee current concepts statement. *British Journal of Sports Medicine, 42*(6), 394-412. DOI: 10.1136/bjsm.2008.048934

20. Sale, D.G., Upton, A.R.M., McComas, A.J., & MacDougall, J.D. (1983). Neuromuscular functions in weight trainers. Experimental Neurology, *82*, 521-531.

21. Solomonow, M., Baratta, R., Zhou, B.H., et al. (1987). The synergistic action of the anterior cruciate ligament and thigh muscles in maintaining joint stability. *American Journal of Sports Medicine*, *15*, 207-213.

22. Williams, C.D. (2017). Rate of Force Development (RFD) - Research and Development in the Biomechanics Lab. https://www.linkedin.com/in/christopher-williams-phd-cscs-340b3143/

23. Wojtys, E.M., & Huston, L.J. (1994). Neuromuscular performance in normal and anterior cruciate ligament-deficient lower extremities. *American Journal of Sports Medicine*, *22*, 89-104.

24. Zech, A., Hübscher, M., Vogt, L., Banzer, W., Hänsel, F., & Pfeifer, K. (2010). Balance training for neuromuscular control and performance enhancement: A systematic review. *Journal of Athletic Training*, *45*(4), 392-403.