ISSN: 2651-4451 • e-ISSN: 2651-446X

Turkish Journal of Physiotherapy and Rehabilitation

2020 31(2)156-162

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Received: *28.04.2019 (Geliş Tarihi)*
Accepted: *14.05.2020 (Kabul Tarihi)*

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AN EXAMINATION OF THIGH MUSCLE ACTIVATIONS IN BRIDGE-PLANK EXERCISES PERFORMED ON DIFFERENT GROUNDS

ORIGINAL ARTICLE

ABSTRACT

Purpose: The study aimed to examine hamstring-quadriceps muscle activations of the supine bridge and reverse plank exercises that are performed for both improving the overall body strength and contributing to the treatment in the process following an injury on different grounds.

Methods: Ten participants (four males and six females, age=26.70±3.02 years) without regular sports habits were included in the study. Bilateral supine bridge and bilateral reverse plank exercises were practiced randomly on stable and unstable grounds. In the study, muscle activation values of vastus medialis (VM), vastus lateralis (VL), biceps femoris (BF) and semitendinosus (SEM) muscles of the participants were examined. Along with the muscle activation that occurred during the exercise, hamstring (BF+SEM)/quadriceps (VM+VL) ratio was also determined (H:Q).

Results: The lowest co-activation ratio (most balanced H:Q activation) was observed on stable ground bridge exercise (5.83±4.04), and the largest co-activation ratio (hamstring dominant activation) was observed on stable ground plank exercise (8.84±6.60). No significant difference was found between exercises at H:Q co-activation ratio (p>0.05). A statistically significant difference was found in the quadriceps and hamstring group in terms of exercise and difference ground in favor of plank (p<0.05).

Conclusion: Reverse plank exercise has greater agonist muscle activation than the supine bridge. Therefore, it is thought that bridge exercise could be advised in the rehabilitation process that necessitates a high level of balance, especially in co-activation ratio. Further study with various clinical problems may direct the process.

Key Words: Electromyography; Exercise; Rehabilitation; Therapeutic.

FARKLI ZEMİNLERDE UYGULANAN BRIDGE-PLANK EGZERSİZLERİNDE UYLUK KAS AKTİVASYONUNUN İNCELENMESİ

ARAŞTIRMA MAKALESİ

ÖZ

Amaç: Araştırmanın amacı, hem genel vücut kuvvetini geliştirmek hem de yaralanma sonrası süreçte tedaviye katkı sağlaması amacıyla farklı zeminlerde uygulanan sırtüstü köprü ve ters plank egzersizlerindeki hamstring-quadriceps kas aktivasyonlarının incelenmesiydi.

Yöntem: Araştırmaya aktif spor yaşantısı olmayan 10 katılımcı (dört erkek ve altı kadın, yaş=26,70±3,02 yıl) dâhil edildi. Randomize olarak sabit ve sabit olmayan zeminlerde bilateral köprü ve bilateral ters plank egzersizleri uygulandı. Araştırmada katılımcıların vastus medialis (VM), vastus lateralis (VL), biceps femoris (BF) ve semitendinosus (SEM) kas aktivasyon seviyeleri incelendi. Egzersiz sırasında meydana gelen kas aktivitesi ile birlikte hamstring (BF+SEM)/quadriceps (VM+VL) oranı da tespit edildi (H:Q).

Sonuçlar: En düşük ko-aktivasyon oranı (en dengeli H:Q aktivasyonu) sabit zemin köprü egzersizinde (5,83±4,04) ve en yüksek ko-aktivasyon oranı (hamstring dominant aktivasyon) sabit zemin plank egzersizinde (8,84±6,60) görüldü. H:Q ko-aktivasyon oranında egzersizler arasında anlamlı farklılık bulunmadı (p>0,05). Egzersiz ve zemin farklılığı açısından hamstring ve quadriceps grubunda plank lehine istatistiksel olarak anlamlı farklılık tespit edildi (p<0,05).

Tartışma: Ters plank egzersizi sırtüstü köprüye göre daha yüksek agonist kas aktivasyonuna sahiptir. Bu sebeple, özellikle yüksek ko-aktivasyon oranı gerektiren rehabilitasyon sürecindeki hastalara köprü egzersizinin tavsiye edilebileceği düşünülmektedir. Değişik klinik sorunlarda yapılacak değerlendirmeler yön gösterici olabilir.

Anahtar Kelimeler: Elektromyografi; Egzersiz; Rehabilitasyon; Terapatik.

INTRODUCTION

Various exercises are performed to obtain overall body strength and to be able to spend the post-injury period in the most efficient way (1,2). The exercises in which the only bodyweight is used are called calisthenic workouts (3). Calisthenic exercises are superior to other exercise modalities in terms of protection of joint health and potential to prevent injury (4). According to the American College of Sports Medicine's exercise preference survey, calisthenic exercises ranked the first in 2015 (5). Plank and bridge exercises are some of the most commonly used calisthenic exercises in terms of both the development of the strength and their therapeutic benefits. Plank and bridge exercises are posture exercises designed to use bodyweight to resist gravity (6). They are known to be beneficial in improving muscular endurance and gaining essential strength (7). It is also known that closed kinetic chain (CKC) exercises are recommended in post-injury process and strengthening (8,9). It is essential to examine the muscle activation patterns that occur in the thigh muscles during reverse plank and supine bridge exercises which could be classified as CKC exercises during the rehabilitation process including anterior cruciate ligament (ACL) injury.

The ground on which the exercise is performed may affect the activation values of the muscles involved in the movement (10,11). Unstable surface exercises are generally considered to be a physiotherapy-focused exercise preference that provides the improvement of proprioceptive neuromuscular control (12). The reason is the increase in the involvement capacity of the synergist or secondary muscles in the activation during exercise to obtain coordination between the muscles. Reducing the workload of the muscles in the single prime mover role could minimize the risk of injury (13). Furthermore, the activation rates of the antagonist muscle or muscle groups are increased in unstable surface exercises (14). The activation rate of the prime mover muscles may be higher during stable surface exercises, inversely proportional to this increase in the antagonist activation on the unstable surface (15). Unstable surface exercises are more beneficial for the body stabilizer muscles rather than the prime mover muscles (16,17).

In addition, the adaptation and the co-activation ratio of the muscles reciprocally functioning during any exercise provide valuable information on whether or not the planned exercise is suitable for the purpose (18). In terms of co-activation, one of the most frequently investigated regions in the literature is the hamstring/quadriceps (H:Q) muscle groups (19-20). One of the rational explanations is that ACL injuries are prevalent in athletes, and there is a significant relationship between ACL injury and H:Q ratio (21,22). The thigh muscles act as the second functional stabilizer of the knee joint (23). It is crucial to examine the H:Q ratio during commonly performed exercises. The expected values of the H:Q ratio may vary depending on the purpose. The co-activation ratio is generally expected to be low (the most balanced) in terms of H:Q in exercises requiring balance and therapy (24). A reduction occurs in the activation of the antagonist muscle after neural adaptation that provides performance enhancement. For this reason, the co-activation ratio has higher values (25). Examining the activation rates of the muscles involved during the exercises for a specific purpose could ensure the choice of the right exercise types.

This study aimed to investigate the hamstring-quadriceps muscle activations in supine bridge and reverse plank exercises performed for both improving the overall body strength on different grounds.

METHODS

This study was carried out from December 3-28, 2018, at Hacettepe University, Faculty of Medicine. At an alpha level of 0.05 and 80% power, we needed 10 participants to detect a significant difference between two different surfaces (stable and unstable) and exercises (bridge and reverse plank). Ten participants (four males and six females) who had not regular sports habits were included in the study. The inclusion criteria were the absence of musculoskeletal problems that would lead to a decrease in the maximum performance of participants. After obtaining the information of demographic and physical characteristics of participants, bilateral supine bridge and bilateral reverse plank exercises were practiced randomly on stable and unstable grounds (advanced stability pad was used as unstable ground). All participants signed written informed consent. The study was approved by the Ethics Committee of Hacettepe University (Approval Date: 20.11.2018 and Approval Number: GO 18/992-08), and conformed to the Helsinki Declaration. Written informed consent was obtained from all participants.

Exercise Procedures

Familiarity phase was performed for all participants before the exercises. After the familiarity phase, the participants randomized to the exercises using a computer-generated block randomization list (26). Exercises were continued isometric for 5 s to avoid fatigue (Figure 1). Muscle activation values for 5 s were included in the analysis.

Electrode Placement and Maximal Voluntary Contraction Test Procedures

Electrode placements followed SENIAM recommendations (27). Before the electrodes were positioned over each muscle, the skin was prepared by shaving, abrading, and cleaning with isopropyl alcohol wipes to reduce skin impedance values. Following the skin preparations, circular bipolar Ag-AgCI surface electrodes (Noraxon Dual Electrodes, Noraxon USA, Scottsdale, Arizona, USA) (diameter=1 cm and interelectrode distance=2 cm) were placed on the volunteer's right side. Vastus medialis (VM), vastus lateralis (VL), biceps femoris (BF) and semitendinosus (SEM) muscles of participants were examined. Before starting exercises, the 5 s 3-repetition maximal voluntary contraction (MVC) values of the hamstring and quadriceps muscle groups of the participants, who were lying in the supine and prone position under the guidance of an expert, were determined by using a fixed belt. In addition, along with the muscle activation that occurred during the exercise, hamstring (BF+SEM)/quadriceps (VM+VL) ratio (H:Q) was also determined.

EMG Signal Processing

Raw sEMG signals were collected using an 8-channel wireless telemetry system (Noraxon Desktop DTS, Scottsdale, AZ, USA) and were analyzed using MyoMuscle MR 3.10 Clinical Applications software (Noraxon Telemyo, Scottsdale, AZ, USA). All raw sEMG signals were first 20-500 Hz Butterworth bandpass filtered, and then RMS (root-mean-square) filtered with a 100 ms time-window for movement artifact rejection and signal smoothing. Each RMS-filtered mean EMG signal of exercises was divided by the highest MVC value to obtain the percentage of maximal muscle contraction (mean %MVC).

Statistical Analysis

Findings were analyzed using GraphPad Prism 7.0 software (GraphPad Software Inc, San Diego, California, USA). Repeated measures ANOVA were used when normally distributed, if not, Friedman test were used to determine ground and exercise differences. If there was a difference between exercises, Tukey (parametric) or Dunn's multiple comparison (nonparametric) tests were performed according to the significance level. Significance level in the study was determined as $p<0.05$. Results were presented graphically, including mean and standard deviations.

RESULTS

When normalized EMG activations are examined, the lowest co-activation ratio (the most balanced H:Q activation) was observed on stable ground bridge exercise (5.83±4.04). The highest co-activation ratio (hamstring dominant activation)

Table 1: Characteristics of the Participants.

Variables	**Participants (n=10)**	
	Mean±SD	**Min-Max**
Age (years)	26.70±3.02	22-32
Gender (Males/Females, n)	4/6	-
Height (cm)	172.80±0.08	1.63-1.86
Weight (kg)	68.48±11.77	53-82
Body Mass Index (kg/m²)	22.82±2.75	18.78-27.72

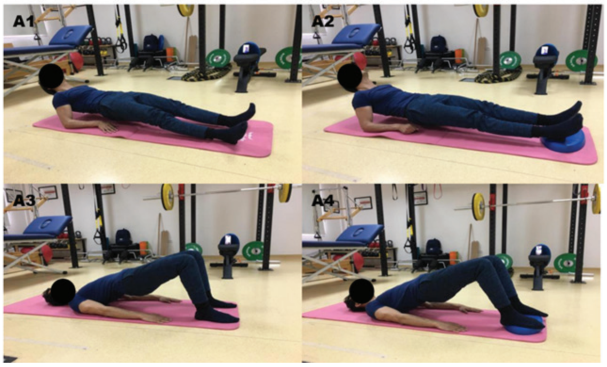


Figure 1: Exercises Performed in the Study. Supine Plank on Stable Surface (A1), on Stability Pad (A2), Supine Bridge on Stable Surface (A3) and on Stability Pad (A4).

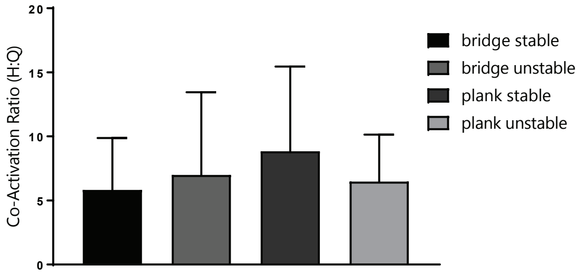
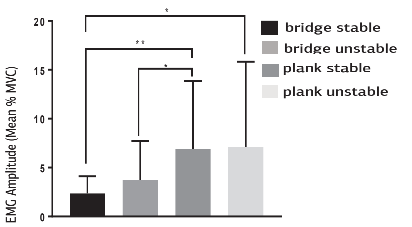
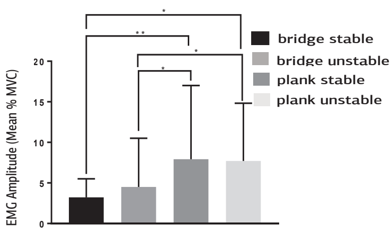


Figure 2: Mean and Standard Deviation of Co-activation Ratio in Terms of Exercise and Ground Difference (H:Q). No Significant Differences across Exercise Variations (p>0.05).

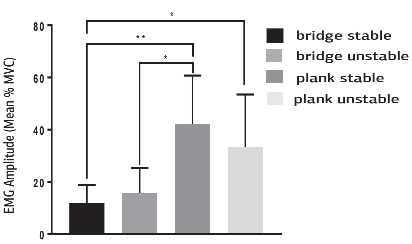
was observed on stable ground plank exercise (8.84±6.60) (Figure 2). No significant difference was found between exercises at H:Q co-activation ratio (Chi-square=2.04, p>0.05). However, a statistically significant difference was found for each muscle in terms of exercise and ground difference (Figure 3-a, 3-b, 3-c, and 3-d). Friedman analysis revealed significant differences between exercises for VM, VL, and BF (Chi-square=20.28, 24.24, and 21.84 respectively, p<0.01). Significant interaction was detected between the activation values in terms of exercise for SEM ($F_{(1.37,12.23)}$= 0.21, p<0.01). When bridge-plank exercises were compared in terms of BF and SEM in the hamstring group, a statistically significant difference was found in favor of plank on stable and unstable grounds (p<0.05). A statistically significant difference was found in VM and VL muscles in the quadriceps in terms of exercise and ground difference in favor of plank (p<0.05). However, there was no significant



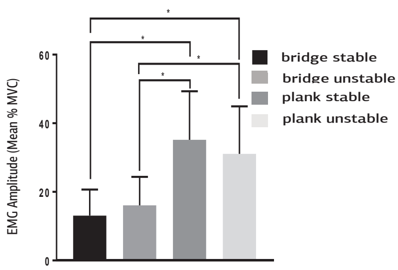
(a) Significantly greater activity *Plank Unstable and **Plank Stable versus Bridge Stable; *Plank Stable versus Bridge Unstable.



(b) Significantly greater activity **Plank Stable and *Plank Unstable versus Bridge Stable; *Plank Stable and *Plank Unstable versus Bridge Unstable.



(c) Significantly greater activity *Plank Unstable and **Plank Stable versus Bridge Stable; *Plank Stable versus Bridge Unstable.



(d) Significantly greater activity *Plank Unstable and *Plank Stable versus Bridge Stable; *Plank Unstable and *Plank Stable versus Bridge Unstable.

(*p<0.05; **p<0.01)

Figure 3: Normalized EMG Activity of (a) Vastus Medialis, (b) Vastus Lateralis, (c) Biceps Femoris, and (d) Semitendinosus across Stable/Unstable Exercises. Significant Difference between Stable/Unstable Exercises (p<0.05).

difference when both exercises were compared in terms of ground differences (p>0.05).

DISCUSSION

In this study, the highest hamstring and quadriceps activation were observed in reverse plank. The most balanced H:Q co-activation ratio was observed in supine bridge exercise on stable ground (28).

Various exercises are performed for rehabilitation. If the exercises performed in the post-injury period, the exercises with low co-activation ratio (the high balanced) are preferred (24). However, in cases where exercise planning to improve the overall strength and muscular endurance, the activation level of the muscles with the primary lifting role in performed exercises could determine the exercise preference. Plank and bridge exercises increase the overall body strength, and could also be used for therapeutic purposes (6,10). In addition, these exercises are frequently preferred in clinical applications because they contain isometric contractions that are suitable for problems such as painful range of motion or muscle weakness (28).

In this study, the quadriceps and hamstring muscle activation of the reverse plank and supine bridge exercises, were investigated in terms of ground difference. The findings obtained from the EMG analyses stated that results in favor of plank for the size of muscle activation. In addition, the results of this study confirmed the hypothesis that the stability ground would produce significant increases in hamstring muscle activation levels in plank exercise. The reason for the greater muscle activation in the hamstring group during stable surface exercises maybe due to a higher activation the prime mover muscles on the stable surface (15).

Lee et al. found the muscle activation size was in favor of unstable ground and suspension system in plank exercise (6). Imai et al. investigated the muscle activations of bridge exercises on the selected muscles, and obtained results in favor of unstable ground in terms of ground difference (29). However, a study by Saeterbakken and Fimland, observed that the muscle activation rates of the pectoralis major and triceps brachia in the prime mover role were in favor of stable surface when the performances during bench press exercise on balance cushion, Swiss ball, and stable bench were compared in terms of surface difference (15). In another study, McBride et al. found results in favor of stable surface in terms of muscle activation rate during one-maximal-repetition squat exercise on the stable and unstable surfaces (using inflated discs under each foot) (30). The fact that the materials used as the unstable ground are not standard types and the differences in parameters such as the joint angle and activation time determined by the practitioner during movement may influence the results (31,32).

It is known that both exercises activate the hamstring group more. The exercises seem like dominant hamstring exercises. The activation of the quadriceps group involved in the antagonist role is also essential because the balance is expected to remain at the optimal level with maximum co-activation in exercises performed stably, especially during the rehabilitation period (19,24). There was hamstring and quadriceps activation in favor of plank in supine bridge and reverse plank exercises. However, supine bridge exercise performed on stable grounds was found to have the lowest co-activation ratio (the most balanced) in this study. The highest co-activation ratio (dominant hamstring activation) was determined in the stable ground plank exercise. A possible explanation for this result is that there is an inverse ratio between the agonist and antagonist muscle groups in terms of muscle activation rate. The rate of muscle activation in the hamstring group during stable surface plank exercise may cause a decrease in the co-activation rate by directly affecting the antagonist muscles (quadriceps groups). Many authors confirmed this finding, and they stated that the prime mover muscles may be more active in stable surface exercises (16,33) and that exercises performed on the unstable surface may be more appropriate in terms of the body stabilizer muscles (17,34). When the natural limits of co-activation are exceeded, a reduction may occur in the practical accuracy of any movement. However, it is thought that increased co-activation may provide benefit for a person who receives assisted walking support during rehabilitation (35). Therefore, it could be stated that the proportional values between the muscles as well as the size of muscle activation arising during exercise should be taken into account when planning training or the treatment. In addition, H:Q ratio is examined in terms of different exercise modalities and variables. Harput et al. examined the H:Q ratio in terms of gender differences and found that women had a higher H:Q ratio than men during side lunge exercise on unstable ground (20). In another study, Youdas et al. found that women had a higher H:Q ratio than men during single-leg squat exercise, but there was no difference between the stable and unstable grounds in terms of H:Q for both sexes (36). These results show that H:Q ratio could be affected by various factors.

The limitations of this study could be expressed as the examination of only the thigh muscles in the study although the related exercises are commonly included in core exercise programs. According to the results of the study, a conclusion could be reached in terms of thigh muscles, but the effectiveness of the exercises could not be interpreted in terms of core strength, especially gluteus maximus and abdominal region. Moreover, the sample consisted of 10 participants may lead to limitations in terms of general interpretation. However, it is possible to see many studies in EMG studies, such sample size (37).

In conclusion, compared with the supine bridge, the reverse plank exercise showed a greater muscle activation on stable and unstable grounds, particularly in the hamstring group. It is thought that while plank exercise contributes more to the development of force, bridge exercise should be advised in the rehabilitation process that necessitates a high level of balance especially in H:Q co-activation ratio. Further study is needed to investigate the characteristics of the exercises used in study various clinical conditions.

Sources of Support: None.

Conflict of Interest: The authors declare no conflict of interest.

Ethical Approval: The study protocol was approved by Hacettepe University Ethics Committee (Approval Date: 20.11.2018 and Approval Number: GO 18/992-08).

Informed Consent: Written informed consent was obtained from participants.

Peer-Review: Externally peer-reviewed.

Author Contributions: Concept – FSÇ, SBÖ, SN, EK, KG, ARS; Design – FSÇ, SBÖ, SN, EK; Supervision – FSÇ, ARS; Resources and Financial Support – FSÇ, KG, ARS; Materials – FSÇ, SBÖ, SN, EK, KG, ARS; Data Collection and/or Processing – FSÇ, SBÖ, SN, EK, KG, ARS; Analysis and/or Interpretation – FSÇ, KG, ARS; Literature Research - FSÇ, SBÖ, SN, EK; Writing Manuscript – FSÇ, ARS; Critical Review – FSÇ, ARS.

Acknowledgements: This study was carried out at Hacettepe University, Faculty of Medicine. This study was presented at the 9th International Biomechanics Congress, Eskişehir, Turkey.

REFERENCES

1. Govil K, Noohu MM. Effect of EMG biofeedback training of gluteus maximus muscle on gait parameters in incomplete spinal cord injury. NeuroRehabilitation. 2013;33(1):147-52.
2. Muthukrishnan R, Shenoy SD, Jaspal SS, Nellikunja S, Fernandes S. The differential effects of core stabilization exercise regime and conventional physiotherapy regime on postural control parameters during perturbation in patients with movement and control impairment chronic low back pain. BMC Sports Sci Med Rehabil. 2010;2(1):1-12.
3. Thomas E, Bianco A, Mancuso EP, Patti A, Tabacchi G, Paoli A, et al. The effects of a calisthenics training intervention on posture, strength and body composition. Isokinet Exerc Sci. 2017;25(3):215-22.
4. Kotarsky CJ, Christensen BK, Miller JS, Hackney KJ. Effect of progressive calisthenic push-up training on muscle strength and thickness. J Strength Cond Res. 2018;32(3):651-9.
5. Thopmson WR. Worldwide survey of fitness trends for 2015: what's driving the market. ACSM'S Health Fit J. 2014;18(6):8-17.
6. Lee J, Jeong K, Lee H, Shin J, Choi J, Kang S, et al. Comparison of three different surface plank exercises on core muscle activity. Phys Ther Rehabil Sci. 2015;5(1):29-33.
7. Byrne JM, Bishop NS, Caines AM, Cranev KA, Feaver AM, Pearcey GE. Effect of using a suspension training system on muscle activation during the performance of a front plank exercise. J Strength Cond Res. 2014;28(11):3049-55.
8. Uçar M, Koca I, Eroglu M, Eroglu S, Sarp U, Arik HO, et al. Evaluation of open and closed kinetic chain exercises in rehabilitation following anterior cruciate ligament reconstruction. J Phys Ther Sci. 2014;26(12):1875-8.
9. Cho SH, Bae CH, Gak HB. Effects of closed kinetic chain exercises on proprioception and functional scores of the knee after anterior cruciate ligament reconstruction. J Phys Ther Sci. 2013;25(10):1239-41.
10. Czaprowski D, Afeltowicz A, Gębicka A, Pawłowska P, Kędra A, Barrios C, et al. Abdominal muscle EMG-activity during bridge exercises on stable and unstable surfaces. Phys Ther Sport. 2014;15(3):162-8.
11. Borreani S, Calatayud J, Martin J, Colado JC, Tella V, Behm D. Exercise intensity progression for exercises performed on

unstable and stable platforms based on ankle muscle activation. Gait Posture. 2014;39(1):404-9.
12. Ferreira LAB, Pereira WM, Rossi LP, Kerpers II, de Paula Jr AR, Oliveira CS. Analysis of electromyographic activity of ankle muscles on stable and unstable surfaces with eyes open and closed. J Bodyw Mov Ther. 2011;15(4):496-501.
13. Anderson KG, Behm DG. Maintenance of EMG activity and loss of force output with instability. J Strength Cond Res. 2004;18(3):637-40.
14. Behm DG, Anderson K, Curnew RS. Muscle force and activation under stable and unstable conditions. J Strength Cond Res. 2002;16(3):416-22.
15. Saeterbakken AH, Fimland MS. Electromyographic activity and 6RM strength in bench press on stable and unstable surfaces. J Strength Cond Res. 2013;27(4):1101-7.
16. Lawrence MA, Carlson LA. Effects of an unstable load on force and muscle activation during a parallel back squat. J Strength Cond Res. 2015;29(10):2949-53.
17. Kim MJ, Oh DW, Park HJ. Integrating arm movement into bridge exercise: effect on EMG activity of selected trunk muscles. J Electromyogr Kinesiol. 2013;23(5):1119-23.
18. Walsh M, Boling MC, McGrath M, Blackburn JT, Padua DA. Lower extremity muscle activation and knee flexion during a jump-landing task. J Athl Train. 2012;47(4):406-13.
19. Dedinsky R, Baker L, Imbus S, Bowman M, Murray L. Exercises that facilitate optimal hamstring and quadriceps co-activation to help decrease ACL injury risk in healthy females: a systematic review of the literature. Int J Sports Phys Ther. 2017;12(1):3-15.
20. Harput G, Soylu AR, Ertan H, Ergun N, Mattacola CG. Effect of gender on the quadriceps-to-hamstrings coactivation ratio during different exercises. J Sport Rehabil. 2014;23(1):36-43.
21. Kim HJ, Lee JH, Ahn SE, Park MJ, Lee DH. Influence of anterior cruciate ligament tear on thigh muscle strength and hamstring-to-quadriceps ratio: a meta-analysis. PLOS One. 2016;11(1):1-11.
22. Harput G, Kilinc HE, Ozer H, Baltaci G, Mattacola CG. Quadriceps and hamstring strength recovery during early neuromuscular rehabilitation after ACL hamstring-tendon autograft reconstruction. J Sport Rehabil. 2015;24(4):398-404.
23. White KK, Lee SS, Cutuk A, Hargens AR, Pedowitz RA. EMG power spectra of intercollegiate athletes and anterior cruciate ligament injury risk in females. Med Sci Sports Exerc. 2003;35(3):371-6.
24. Begalle RL, DiStefano LJ, Blackburn T, Padua DA. Quadriceps and hamstrings coactivation during common therapeutic exercises. J Athl Train. 2012;47(4):396-405.
25. Hakkinen K, Kallinen M, Izquierdo M, Jokelainen K, Lassila H, Malkia E, et al. Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people. J Appl Physiol. 1998;84(4):1341-9.
26. Urbaniak GC, Plous S. Research Randomizer (Version 4.0) [Computer software]. Retrieved on December 2018, from http://www.randomizer.org/
27. Project SENIAM. Surface Electromyography for the non-invasive assessment of muscles; 2011. Available at: www.seniam.org. Access Date: 26.02.2019.
28. Andrade R, Araújo RC, Tucci HT, Martins J, Oliveira AS. Coactivation of the shoulder and arm muscles during closed kinetic chain exercises on an unstable surface. Singapore Med J. 2011;52(1):35-41.
29. Imai A, Kaneoka K, Okubo Y, Shiina I, Tatsumura M, Izumi S, et al. Trunk muscle activity during lumbar stabilization exercises on both a stable and unstable surface. J Orthop Sports Phys Ther. 2010;40(6):369-75.
30. McBride JM, Larkin TR, Dayne AM, Haines TL, Kirby TJ. Effect of absolute and relative loading on muscle activity during stable and unstable squatting. Int J Sports Physiol Perform. 2010;5(2):177-83.
31. Calatayud J, Colado JC, Martin F, Casaña J, Jakobsen MD, Andersen LL. Core muscle activity during the clean and jerk lift with barbell versus sandbags and water bags. Int J Sports Phys Ther. 2015;10(6):803-10.
32. Kohler JM, Flanagan SP, Whiting WC. Muscle activation patterns while lifting stable and unstable loads on stable and unstable surfaces. J Strength Cond Res. 2010;24(2):313-21.
33. Anderson K, Behm DG. Trunk muscle activity increases with unstable squat movements. Can J Appl Physiol. 2005;30(1):33-45.
34. Anderson GS, Gaetz M, Holzmann M, Twist P. Comparison of EMG activity during stable and unstable push-up protocols. European J Sport Sci. 2013;13(1):42-8.
35. Reeves NP, Everding VQ, Cholewicki J, Morrisette DC. The effects of trunk stiffness on postural control during unstable seated balance. Exp Brain Res. 2006;174(4):694-700.
36. Youdas JW, Hollman JH, Hitchcock JR, Hoyme GJ, Johnsen JJ. Comparison of hamstring and quadriceps femoris electromyographic activity between men and women during a single-limb squat on both a stable and labile surface. J Strength Cond Res. 2007;21(1):105-11.
37. Kim T, Kim M, Lee M, Yoon B. Comparison of scapular muscle activation during shoulder elevation in older and young adults: A pilot study. J Back Musculoskelet. 2019;32(3):437-43.