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The Relationship Between Eccentric Hamstring Muscle Strength and Reaction Time in Elite Volleyball Players: Cross-Sectional Study

Elit Voleybolcularda Eksantrik Hamstring Kas Kuvveti ile Reaksiyon Süresi Arasındaki İlişki: Kesitsel Çalışma

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ABSTRACT Objective: The aim of this study was to investigate whether or not eccentric hamstring muscle strength has an effect on reaction time in elite volleyball players. **Material and Methods:** The study included 33 male volleyball players, aged 16-20 years, who met the study inclusion criteria. The eccentric hamstring strength was measured during Nordic hamstring exercises with an iVMES H-BORD®. The reaction time of the volleyball players was measured with the Light Trainer Flash Light Exercise System™. **Results:** A strong level, negative, significant correlation was determined between the maximum eccentric hamstring muscle strength values of the dominant and non-dominant side of the study participants and the mean reaction time ($r=-0.69$, $p<0.001$; $r=-0.78$, $p<0.001$, respectively) and the best reaction time values ($r=-0.70$; $p<0.001$, $r=-0.75$; $p<0.001$, respectively). A strong level, negative, significant correlation was determined between the mean eccentric hamstring muscle strength values of the dominant and non-dominant side and the mean reaction time ($r=-0.69$; $p<0.001$, $r=-0.71$; $p<0.001$, respectively) and the best reaction time values ($r=-0.71$; $p<0.001$, $r=-0.68$; $p<0.001$, respectively). At the same time, it was determined that there was no significant correlation between maximum and mean eccentric muscle strength difference and mean reaction time and best reaction time values ($p>0.05$). **Conclusion:** The results of this study showed a significant correlation between eccentric hamstring muscle strength and reaction time parameters in young, male volleyball players. Trainers and sports scientists should take this into consideration in training programs to improve the performance of volleyball players.

Keywords: Volleyball; eccentric muscle strength; hamstring; reaction time

ÖZET Amaç: Bu çalışmanın amacı, elit voleybol oyuncularında eksantrik hamstring kuvvetinin reaksiyon zamanı üzerine etkili olup olmadığını araştırmaktır. **Gereç ve Yöntemler:** Çalışmaya dahil edilme kriterlerini karşılayan 16-20 yaş arası 33 erkek voleybol oyuncusu dahil edilmiştir. Eksantrik hamstring kuvveti Nordic hamstring egzersizi sırasında iVMES H-BORD® cihazı ile ölçülmüştür. Sporcuların reaksiyon zamanı Light Trainer Flash Light Exercise System™ reaksiyon zamanı cihazı ile yapılmıştır. **Bulgular:** Çalışmaya katılan bireylerin dominant ve nondominant taraf maksimum eksantrik hamstring kas kuvvetleri ile ortalama alt ekstremite reaksiyon zamanı (sırasıyla $r=-0,69$, $p<0,001$; $r=-0,78$, $p<0,001$) ve en iyi reaksiyon zamanı (sırasıyla $r=-0,70$; $p<0,001$, $r=-0,75$; $p<0,001$) değerleri arasında kuvvetli, ters yönde, anlamlı ilişki olduğu saptanmıştır. Benzer şekilde dominant ve nondominant taraf ortalama eksantrik hamstring kas kuvvetleri ile ortalama alt ekstremite reaksiyon zamanı (sırasıyla $r=-0,69$; $p<0,001$, $r=-0,71$; $p<0,001$) ve en iyi reaksiyon zamanı (sırasıyla $r=-0,71$; $p<0,001$, $r=-0,68$; $p<0,001$) değerleri arasında anlamlı, kuvvetli, ters yönde ilişki olduğu bulunmuştur. Aynı zamanda maksimum ve ortalama eksantrik kas kuvvet farklılığı ile ortalama alt ekstremite reaksiyon zamanı ve en iyi reaksiyon zamanı değerleri arasında ise anlamlı bir ilişki olmadığı tespit edilmiştir ($p>0,05$). **Sonuç:** Sonuç olarak, voleybolcularda eksantrik hamstring kuvveti ile reaksiyon zamanı parametreleri arasında anlamlı ilişki olduğu bulunmuştur. Voleybolcuların performanslarını geliştirmek için çalışan atletik performans antrenörleri ve spor bilimciler bu durumu göz önünde bulundurmalıdırlar.

Anahtar Kelimeler: Voleybol; eksantrik kas kuvveti; hamstring; reaksiyon zamanı

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Volleyball is a sport that is played in a relatively small area, with repeated rapid movements requiring agility and rapid lift-offs, and explosive movements such as smashing and blocking that require vertical jumps. Therefore, in the development of lower extremity muscle strength, it becomes necessary to generate a high level of force at high speed.[1,2] Due to the importance of muscle strength to develop power in jumping performance, a strength imbalance in the lower extremities can have a negative effect on the jumping of volleyball players and can lead to injuries.[3] The most common muscle injuries affecting volleyball players are injuries to the hamstring, rectus femoris, and medial gastrocnemius with the deltoid anterior, respectively.[4]

The hamstrings are the muscle group at highest risk and with the highest injury rate. When the factors causing hamstring muscle injuries (HMI) are examined, these include a history of hamstring injury, weak eccentric knee flexor muscle strength, imbalance in the hamstring: quadriceps ratio, delayed reaction time, transverse pelvic posture (pelvis anterior tilt and increased lumbar lordosis), weak lumbopelvic stability, cognitive function, and deteriorated hamstring muscle architecture.[5] When excursion capacity of the hamstrings is taken into consideration according to the muscle architecture properties, it has been suggested that weakness in eccentric strength or imbalance between the extremities lays the ground for HMI, and both these factors have been associated with the risk of HMI in many sports branches, and especially in volleyball.[6]

The data reported in several studies have shown that eccentric muscle strength supports muscle hypertrophy and is the most effective stimulus to increase the neural stimulus going to the muscle.[7] Muscle performance has generally been investigated with muscle contraction and the neural structure adaptations this creates. However, reaction time is another component that affects muscle performance. Reaction time is defined as the time from the application of a stimulus to the emergence of an appropriate voluntary response from the subject in the shortest possible time. This is a measurement of the sensorimotor function and performance of an individual. Stimulus processing includes decision-making and reaction programming. The importance of reaction time in sport is that the fine motor skills are developed in certain movements for athletes, and this develops as a result of the comprehensive application of the relevant movements in athletic situations.

A rapid reaction time in athletes requires advanced concentration, better muscle co-ordination, and advanced performance in rapid and sensitive tasks. Rapid reaction time is useful in sports such as volleyball, football, basketball, and tennis.[8] In sports such as volleyball, basketball, and boxing, which require rapid changes in stance, reaction time seems to be important when the player moves according to the status of the ball or the opponent, or in swimming and athletics for starting a movement at the moment the signal is given.[9,10] Therefore, evaluation of reaction time and emphasis on its importance is necessary for the guidance of athletes and sports scientists working in this field. Although there are many factors which have a positive or negative effect on reaction time, whether or not there is a relationship with eccentric hamstring muscle strength has not been addressed in the literature. The aim of this study was to investigate whether or not eccentric hamstring muscle strength has an effect on reaction time in professional volleyball players. The hypothesis of the study was that athletes with higher eccentric hamstring muscle strength would have better reaction time scores.

MATERIAL AND METHODS

STUDY PARTICIPANTS

This prospective, descriptive research study was planned to examine the effect of eccentric hamstring strength on reaction time in healthy, male volleyball players, playing in the U16-U20 leagues. Approval for the study was granted by the Ethics Committee of KTO Karatay University (date: March 31, 2023; no: 2023/003,). All procedures were applied in compliance with the principles of the Helsinki Declaration.

The study inclusion criteria for the inclusion of healthy male volleyball players aged 16-20 years were defined as (a) age between 16 and 20 years, (b) no soft tissue or orthopaedic injury in the trunk, hips, or lower extremities, (c) no history of hamstring strain or ligamentous injury related to the knee, (d)

being an active volleyball player, (e) no known neurological or systemic problem, and (f) voluntary participation in the study.

Subjects were excluded from the study if they had a history of lower extremity injury and/or hamstring strain within the last year, if they had any musculoskeletal, neurological, respiratory, or cardiovascular risk factor which would limit the tests to be applied, or if they had contracted coronavirus disease-2019 infection within the last 6 months.

Sample size was determined using G*Power version 3.0.10 software (Universitat Kiel, Germany). The primary outcome measurement of the study was the relationship between eccentric hamstring strength and reaction time, and to be able to obtain 5% Type 1 error, 80% power, and effect size of f=0.40 (f>10: small, f>0.25: moderate, f>0.40: large), it was calculated to be necessary to include at least 30 subjects in the study.[11,12] Taking into consideration, the potential loss of 20% of the subjects, a total of 33 volleyball players were enrolled. All the study participants provided informed consent for voluntary participation in the study before it was started.

DATA COLLECTION TOOLS

A record was made of demographic characteristics of the study participants, including age, height, weight, body mass index (BMI), and dominant extremity. The dominant lower extremity was defined as the extremity from which the player took off when jumping.[13] The eccentric hamstring strength was measured during Nordic hamstring exercises with an iVMES H-BORD® (iVMES, Ankara, Türkiye) device (Figure 1). The reaction time of the volleyball players was measured with the Light Trainer Flash Light Exercise System™ (FitLight Corp, Ontario, Canada).

Eccentric Hamstring Muscle Strength

The Nordic Hamstring Curl (NHC) has been shown to be an effective and reliable method in the training of eccentric hamstring strength. The validity and reliability of this exercise to evaluate eccentric hamstring strength has been reported in literature, and with the use of an H-Bord, it has become a rapid, simple, accurate, and reliable method for the monitoring of hamstring strength and imbalance.[14] In this study, the NHC was applied using the iVMES H-BORD (iVMES, Ankara, Türkiye, Software version: 1.0). The participant to whom the test was applied was instructed to kneel on the board and a stabilising hook attached to sensors was passed over both ankles. Following a warm-up set, the participants performed 1 set of bilateral Nordic hamstring exercises with 3 repetitions. During the tests, each subject was instructed to lean forward slowly lowering themselves to the floor on their palms until they were unable to maintain the eccentric hamstring contraction. Throughout each repetition, the subjects were encouraged verbally to make maximum effort. If the subject lost control while lowering to the floor or showed excessive hip movement during the repetition, these repetitions were not included.[14,15]

Reaction Time

In the evaluation of the extremity reaction time of the volleyball players, the Light Trainer Flash Light Exercise System™ reaction time device was used (intraclass correlation: 0.89).[16] Packages are available from 4 to 32 spots. As part of our research, we had 2 packages of 8 spotlights, each with default software (Software version: 4.0.32). The results of the software can also be downloaded and viewed through applications on mobile phones or laptops. The measurements were performed on the same day in a quiet, well-lit environment. Three light reaction modules at intervals of 300 cm were placed on a net 20 cm in front of the subject. Each subject performed a trial before the test, then was instructed to stand at the starting point for the test. The commands of ready and start were given, then the subject waiting on the starting point started the test from number 3. The test was started on the signal of the middle light flashing 3 times. The lights came on in random order from 3 areas. Each time the participant came to number 3, he waited for the next light. The system was set so that after each light went out, there was a 3-second delay for it to come on again. The test was terminated when the subject put out 6 randomly lit lights. For the subject to put out the lights, a vertical jump was made at number 3, and transverse step block step at numbers 2 and 4 (Figure 1). The reactions shown to the light stimuli were measured throughout 30 sec-

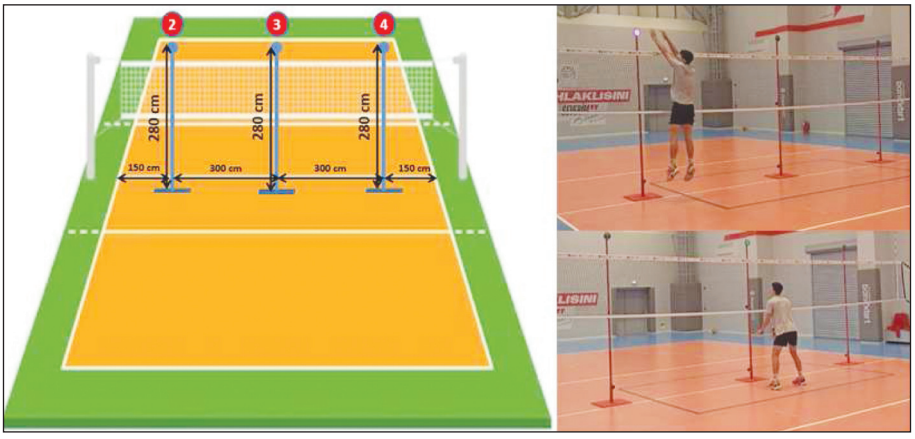

FIGURE 1: Measurement of reaction time with the Light Trainer Flash Light Exercise System™.

onds. The test was applied 3 times, after which the mean reaction time was calculated, and this was recorded together with the fastest reaction time.[16]

STATISTICAL ANALYSIS

Data obtained in the study were analyzed statistically using SPSS Version 26 (IBM SPSS® software, US). Conformity of the variables to normal distribution was assessed with visual (histogram, probability graphs) and statistical methods (Kolmogorov-Smirnov test, Shapiro-Wilk test). The relationship between eccentric hamstring muscle strength and reaction time parameters was analyzed with the Spearman Rho correlation test. In all of the statistics, p significance level was accepted as $p<0.05$ and weak correlation at r=0.1-0.3, moderate correlation at r=0.31-0.5 and strong correlation at r>0.5. [17]

RESULTS

A total of 33 participants were included in this study. The average age and BMI of athletes were 16.9±1.08 years and 20.7±1.07 kg/m^2, respectively. The right side was dominant in 78.8% (n=26) of the athletes.

A strong level, negative, significant correlation was determined between the maximum eccentric hamstring muscle strength values of the dominant and non-dominant side of the study participants and the mean reaction time (r=-0.69, $p<0.001$; r=-0.78, $p<0.001$, respectively) and the best reaction time values (r=-0.70; $p<0.001$, r=-0.75; $p<0.001$, respectively). A strong level, negative, significant correlation was determined between the mean eccentric hamstring muscle strength values of the dominant and non-dominant side and the mean reaction time (r=-0.69; $p<0.001$, r=-0.71; $p<0.001$, respectively) and the best reaction time values (r=-0.71; $p<0.001$, r=-0.68; $p<0.001$, respectively) (Table 1).

At the same time, it was determined that there was no significant correlation between maximum and mean eccentric muscle strength difference and mean reaction time and best reaction time values ($p>0.05$) (Table 2).

TABLE 1: Correlations between eccentric hamstring muscle strength parameters and reaction time.

	D-Maximum Hecc (N)		ND-Maximum Hecc (N)		D-Mean Hecc (N)		ND-Mean Hecc (N)	
	rho	p value	rho	p value	rho	p value	rho	p value
Mean reaction time (s)	**-0.69****	<0.001	**-0.78****	<0.001	**-0.69****	<0.001	**-0.71****	<0.001
Best reaction time (s)	**-0.70****	<0.001	**-0.75****	<0.001	**-0.71****	<0.001	**-0.68****	<0.001

****p<0.01**; rho: Spearman correlation coefficient; Hecc: Eccentric hamstring muscle strength; N: Newton.

TABLE 2: Correlations between eccentric hamstring muscle strength difference percentage and reaction time.

	Maximum muscle difference (%)		Mean muscle difference (%)	
	rho	p value	rho	p value
Mean reaction time (s)	0.21	0.244	0.11	0.528
Best reaction time (s)	0.17	0.339	0.06	0.746

rho: Spearman correlation coefficient.

DISCUSSION

The most significant finding of this study was the determination of a significant negative correlation between reaction time and the eccentric hamstring muscle strength of both side, and no correlation was shown with bilateral muscle strength differences.

This study demonstrated that volleyball players with high dominant side eccentric hamstring muscle strength showed more rapid reaction time performance. Previous cross-sectional studies have shown a relationship between muscle strength and reaction time. In one study it was stated that high muscle strength (measured as hand grip strength) was related to reaction time and even protected cognitive function.[18] Similarly, another study of participants aged 70-75 years, which examined the relationship of hand grip strength with reaction time, showed that as reaction time decreased, the hand grip strength values increased.[19] A study of adults in Japan reported that those with high cognitive function scores had both higher grip strength in the right hand and greater isometric knee extensor muscle strength.[20] Although all three studies suggested that there is a significant relationship between muscle strength and reaction time, to the best of our knowledge there is no study in the literature that has investigated the effect of eccentric knee muscle strength on reaction time in volleyball players. Therefore, this is the first study to have shown the extent of the effect of eccentric hamstring muscle strength on reaction time in volleyball players.

Reaction time is an important component of successful sports performance as it allows athletes to give a rapid reaction to varying and often imbalanced environments. Generally, reaction time includes all basic body movements that are required for the athlete to be successfully competitive and be synchronised to be able to prevent injury.[21] It is required in many sports from taking possession of the ball in football, baseball, and softball, to deciding to whom to pass the ball to in volleyball and basketball. In sports matches athletes generally have to make a decision to select from more than one stimulus which can lead to different outcomes depending on the selection made. Correct identification of the stimuli presented and having the ability to move accordingly can make the difference between success and failure and even between sustaining an injury or not.

Neural adaptations, which play a role in the occurrence of effective muscle contraction, are separated into two as intramuscular and intermuscular co-ordination. Intermuscular co-ordination is the capacity to co-ordinate kinetic chain cycles of the nervous system, thereby rendering the movement more productive. The development of co-ordination between muscles depends on the learning technique. Over time, as the nervous system learns the movement, fewer motor units are activated with the same weight, causing more motor units to remain open to activation by higher weights.[22,23] Therefore, these mechanisms can be explained by individuals with more rapid reaction time having greater eccentric hamstring muscle strength.

The other hypothesis of this study was established to examine the relationship between reaction time and the percentage difference of muscle strength between the two sides. The results of the reaction time analysis, which was conducted for this purpose in the context of this study, demonstrated no significant correlation with the percentage difference in eccentric muscle strength between the two sides. Although the results were not significant, it was determined that the percentage difference in muscle

strength between the two sides of the volleyball players with high reaction time was above 10%, which is accepted as the limit for injury, and thus they were at risk of injury. These results are consistent with the results of many studies in literature, and the majority of current evidence has reported that deficits in reaction time can render athletes vulnerable to injury.[24]

The multidimensional role of hamstring strength in athletic performance is well understood and the direct contribution of hamstring strength to athletic skills such as sprinting and jumping has been demonstrated in several studies.[25,26] Hamstring strength also plays an important role in knee joint stabilisation, indirectly influencing the qualities of agility manoeuvres such as acceleration, deceleration, changing direction and cutting.[27] It has also been suggested that hamstring weakness increases the risk of anterior cruciate ligament (ACL), a typical sports injury that occurs in sports such as athletics and volleyball, which require high sprint speed and/or simultaneous excessive muscle tension.[28] Low hamstring strength or inadequate activation is associated with non-contact ACL injuries, which are particularly high in team sports such as football and volleyball. In particular, as a synergist of the ACL, the lateral hamstring muscle spans two joints and provides secondary protection, especially at the smaller joint angle.[29] Specifically, during unexpected jumping-recoil or jumping movements, individuals with a worse reaction time demonstrate reaction forces at a higher place, knee abduction moments, tibial anterior shear forces, oscillations, and smaller hamstring:quadriceps muscle strength ratios.[30-32] It is assumed that changes in the movement biomechanics can mediate the effect of reaction time on the risk of injury.

A limitation of this study was that it was only conducted on male U16-U20 volleyball players. Further studies should be expanded by including female volleyball players and those in other leagues.

CONCLUSION

In conclusion, the results of this study demonstrated a significant relationship at above average levels between eccentric hamstring strength and reaction time parameters in young, male volleyball players. Trainers and sports scientists should take this into consideration when designing training programs to improve the performance of volleyball players.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

All authors contributed equally while this study preparing.

REFERENCES

1. Sattler T, Sekulic D, Esco MR, Mahmutovic I, Hadzic V. Analysis of the association between isokinetic knee strength with offensive and defensive jumping capacity in high-level female volleyball athletes. J Sci Med Sport. 2015;18(5):613-8. [Crossref] [PubMed]
2. Schons P, Da Rosa RG, Fischer G, Berriel GP, Fritsch CG, Nakamura FY, et al. The relationship between strength asymmetries and jumping performance in professional volleyball players. Sports Biomech. 2019;18(5):515-26. [Crossref] [PubMed]
3. Pupo JD, Detanico D, Santos SGD. Kinetic parameters as determinants of vertical jump performance. Revista Brasileira de Cineantropometria & Desempenho Humano. 2012;14:41-51. [Link]
4. Tamin TZ, Murdana IN, Kekalih A. Hamstring muscle flexibility among KONI volleyball players of DKI Jakarta province-a pilot study for sport injury prevention. Indonesian Journal of Physical Medicine & Rehabilitation. 2013;2(01):115-31. [Crossref]
5. Martin RL, Cibulka MT, Bolgla LA, Koc TA Jr, Loudon JK, Manske RC, et al. Hamstring strain injury in athletes. J Orthop Sports Phys Ther. 2022;52(3):CPG1-CPG44. [Crossref] [PubMed]
6. Bourne MN, Opar DA, Williams MD, Shield AJ. Eccentric knee flexor strength and risk of hamstring injuries in rugby union: a prospective study. Am J Sports Med. 2015;43(11):2663-70. [Crossref] [PubMed]
7. Hedayatpour N, Falla D. Physiological and neural adaptations to eccentric exercise: mechanisms and considerations for training. Biomed Res Int. 2015;2015:193741. [Crossref] [PubMed] [PMC]

8. Shejwal K, Kumar N. Comparison of simple reaction time between volleyball and football playing collegiate athletes. Int J Res Anal. 2020;7(2):421-4. [Link]
9. Ceylan H, Günay A. Positional differences in anticipation timing, reaction time and dynamic balance of American football players. Pedagogy of Physical Culture and Sports. 2020;24(5):227-39. [Crossref]
10. Badau D, Baydil B, Badau A. Differences among three measures of reaction time based on hand laterality in individual sports. Sports (Basel). 2018;6(2):45. [Crossref] [PubMed] [PMC]
11. Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods. 2007;39(2):175-91. [Crossref] [PubMed]
12. Lakens D. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. Front Psychol. 2013;4:863. [Crossref] [PubMed] [PMC]
13. Soylu Ç, Altundağ E, Akarçeşme C, Ün Yildirim N. The relationship between isokinetic knee flexion and extension muscle strength, jump performance, dynamic balance and injury risk in female volleyball players. Journal of Human Sport and Exercise. 2020;15(3):502-14. [Crossref]
14. Opar DA, Piatkowski T, Williams MD, Shield AJ. A novel device using the Nordic hamstring exercise to assess eccentric knee flexor strength: a reliability and retrospective injury study. J Orthop Sports Phys Ther. 2013;43(9):636-40. [Crossref] [PubMed]
15. Opar DA, Williams MD, Timmins RG, Hickey J, Duhig SJ, Shield AJ. Eccentric hamstring strength and hamstring injury risk in Australian footballers. Med Sci Sports Exerc. 2015;47(4):857-65. [Crossref] [PubMed]
16. Myers LR, Toonstra JL, Cripps AE. The test-retest reliability and minimal detectable change of the FitLight Trainer™. International Journal of Athletic Therapy and Training. 2022;28(2):84-8. [Crossref]
17. Lakens D. Equivalence tests: a practical primer for t tests, correlations, and meta-analyses. Soc Psychol Personal Sci. 2017;8(4):355-62. [Crossref] [PubMed] [PMC]
18. Jiménez-García JD, Martínez-Amat A, Hita-Contreras F, Fábrega-Cuadros R, Álvarez-Salvago F, Aibar-Almazán A. Muscle strength and physical performance are associated with reaction time performance in older people. Int J Environ Res Public Health. 2021;18(11):5893. [Crossref] [PubMed] [PMC]
19. Abellan van Kan G, Cesari M, Gillette-Guyonnet S, Dupuy C, Nourhashémi F, Schott AM, et al. Sarcopenia and cognitive impairment in elderly women: results from the EPIDOS cohort. Age Ageing. 2013;42(2):196-202. [Crossref] [PubMed]
20. Takata Y, Ansai T, Soh I, Kimura Y, Yoshitake Y, Sonoki K, et al. Physical fitness and cognitive function in an 85-year-old community-dwelling population. Gerontology. 2008;54(6):354-60. [Crossref] [PubMed]
21. Lempke LB, Howell DR, Eckner JT, Lynall RC. Examination of reaction time deficits following concussion: a systematic review and meta-analysis. Sports Med. 2020;50(7):1341-59. [Crossref] [PubMed]
22. Griffin L, Cafarelli E. Resistance training: cortical, spinal, and motor unit adaptations. Can J Appl Physiol. 2005;30(3):328-40. [Crossref] [PubMed]
23. Folland JP, Williams AG. The adaptations to strength training : morphological and neurological contributions to increased strength. Sports Med. 2007;37(2):145-68. [Crossref] [PubMed]
24. Wilke J, Groneberg DA. Neurocognitive function and musculoskeletal injury risk in sports: a systematic review. J Sci Med Sport. 2022;25(1):41-5. [Crossref] [PubMed]
25. Váczi M, Fazekas G, Pilissy T, Cselkó A, Trzaskoma L, Sebesi B, et al. The effects of eccentric hamstring exercise training in young female handball players. Eur J Appl Physiol. 2022;122(4):955-64. [Crossref] [PubMed] [PMC]
26. Markovic G, Sarabon N, Boban F, Zoric I, Jelcic M, Sos K, et al. Nordic hamstring strength of highly trained youth football players and its relation to sprint performance. J Strength Cond Res. 2020;34(3):800-7. [Crossref] [PubMed]
27. Greig M, Naylor J. The efficacy of angle-matched isokinetic knee flexor and extensor strength parameters in predicting agility test performance. Int J Sports Phys Ther. 2017;12(5):728-36. [Crossref] [PubMed] [PMC]
28. Lee JWY, Mok KM, Chan HCK, Yung PSH, Chan KM. Eccentric hamstring strength deficit and poor hamstring-to-quadriceps ratio are risk factors for hamstring strain injury in football: a prospective study of 146 professional players. J Sci Med Sport. 2018;21(8):789-93. [Crossref] [PubMed]
29. Zebis MK, Andersen LL, Bencke J, Kjaer M, Aagaard P. Identification of athletes at future risk of anterior cruciate ligament ruptures by neuromuscular screening. Am J Sports Med. 2009;37(10):1967-73. [Crossref] [PubMed]
30. Herman DC, Barth JT. Drop-jump landing varies with baseline neurocognition: implications for anterior cruciate ligament injury risk and prevention. Am J Sports Med. 2016;44(9):2347-53. [Crossref] [PubMed] [PMC]
31. Shibata S, Takemura M, Miyakawa S. The influence of differences in neurocognitive function on lower limb kinematics, kinetics, and muscle activity during an unanticipated cutting motion. Phys Ther Res. 2018 30;21(2):44-52. [Crossref] [PubMed] [PMC]
32. Giesche F, Wilke J, Engeroff T, Niederer D, Hohmann H, Vogt L, et al. Are biomechanical stability deficits during unplanned single-leg landings related to specific markers of cognitive function? J Sci Med Sport. 2020;23(1):82-8. [Crossref] [PubMed]