THE EFFECT OF INSTABILITY RESISTANCE TRAINING ON NEUROMUSCULAR PERFORMANCE IN ATHLETES AFTER ANTERIOR CRUCIATE LIGAMENT INJURY

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Abstract

The study evaluates effects on static and dynamic balance, speed of step initiation and the soccer kick after instability resistance training in athletes after ACL injury. A group of 14 soccer players (age 21.8 ± 3.4 y, height 182.2 ± 5.6 cm, and weight 76.7 ± 4.8 kg) underwent two months after rehabilitation a combined resistance and balance exercises (in duration of 30 min) for a period of 12-weeks (4-5 sessions/week). Postural stability was evaluated under both static and dynamic conditions (wobble board and antero-posterior / medio-lateral tilted platforms) during bipedal and one-legged stance. The COP velocity was registered at 100 Hz by means of posturography system FiTRO Sway check based on dynamometric platform. Speed of step initiation and the soccer kick was measured using FiTRO Dyne Premium. Pre-training measurements showed the non-injured-to-injured leg percent differences of 15.7% for static and 24.5% for dynamic balance. Following the training there were no changes in static balance on both legs (from 18.2 ± 3.3 mm/s to 15.8 ± 2.8 mm/s), on non-injured leg (from 41.3 ± 8.8 mm/s to 38.2 ± 7.8 mm/s), and on injured leg (from 49.0 ± 8.9 mm/s to 43.2 ± 7.7 mm/s). Likewise, the dynamic balance did not change while standing on both legs (from 95.2 ± 19.0 mm/s to 86.7 ± 17.8 mm/s) and on non-injured leg (from 112.3 ± 25.0 mm/s to 101.2 ± 21.8 mm/s), however a significant ($p \leq 0.01$) improvement on injured leg has been found (from 148.7 ± 22.8 mm/s to 118.0 ± 20.0 mm/s). In addition, the COP velocity significantly ($p \leq 0.05$) decreased during bipedal stance on M-L tilted platform (from 134.2 ± 20.1 mm/s to 110.6 ± 18.2 mm/s) but not on those A-P tilted (from 120.6 ± 19.7 mm/s to 104.7 ± 18.0 mm/s). Furthermore, mean run-out speed significantly ($p \leq 0.05$) increased on injured leg (from 347.4 ± 42.3 cm/s to 385.3 ± 38.8 cm/s) but not on non-injured leg (from 378.1 ± 42.1 cm/s to 371.8 ± 47.1 cm/s). However, no changes in mean kick-off speed on injured and non-injured leg have been found (from 474.0 ± 38.5 cm/s to 515.6 ± 43.3 cm/s and from 475.9 ± 40.7 cm/s to 499.5 ± 37.6 cm/s). It may be concluded that resistance exercises performed on unstable surfaces represent an effective means for the improvement of dynamic balance under various conditions and speed of step initiation in athletes after ACL injury. However more specific exercises should be implemented into training program in order to improve sport-specific skills like the kick-off speed.

***Key words**: athletes, ACL-injury, instability resistance training*

Introduction

Traumatic injuries of the knee joint leading to anterior cruciate ligament (ACL) tears are frequent in sport. After conservative treatment some of the individuals return to their preinjury functional level, whereas others present with functional instability. Among the variables that might be related to the presence of functional instability caused by ACL deficiency, deficits in proprioceptive mechanisms have received considerable attention. In most of the studies (e.g., Barrack et al., 1989; Corrigan et al., 1992; MacDonald et al., 1996; Roberts et al., 1999) a reduction in proprioceptive acuity in individuals with ACL injuries has been demonstrated. In particular, higher threshold of perception of passive motion in individuals with ACL rupture when compared to healthy controls (Roberts et al., 1999) and when compared injured and non-injured legs of individuals with ACL damage (Barrack et al., 1989; MacDonald et al., 1996) has been found. In addition, repositioning errors have been documented as a result of ACL injury (Barret, 1991; Corrigan et al., 1992). On the other hand, a few studies failed to demonstrate these deficits in individuals with ACL injury (Friden et al., 1998; Good et al., 1999). Fonseca et al (2005) proved that individuals with good functional and muscular performance did not present proprioceptive deficits measured throught tests of position sense and threshold of detection of passive movement. It may be assumed that a decline in functional and muscular performance could also lead to a reduction in proprioceptive acuity. It is therefore important to continue in rehabilitation after conservative treatment in order to maintain or even improve the performance.

Currently, instability resistance exercises in combination with sport-specific drills used to be applied in post-rehabilitation period when training is carried out in the playing field or gym. These exercise programs should be designed to match particular sport activity in order to achieve the improvement in sport-specific neuromuscular performance. The aim of the study was to evaluate effects on static and dynamic balance, speed of step initiation and the soccer kick after instability resistance training in athletes undergoing rehabilitation after ACL injury.

Methods

Subjects
A group of 14 soccer players after ACL injury (age 21.8 ± 3.4 y, height 182.2 ± 5.6 cm, and weight 76.7 ± 4.8 kg) volunteered to participate in the study. All of them were informed of the procedures and of the main purpose of the study.

Study setting
Subjects underwent, two months after conservative treatment, a combined resistance and balance exercises (in duration of 30 min) for a period of 12-weeks (4-5 sessions/week) (Fig. 1). Professional instructor was involved to provide individually designed training programs. The intervention included besides balancing and strengthening exercises, and forward and side-by-side run-out movements, also soccer-specific drills.

Diagnostic equipments
Postural stability was evaluated under both static and dynamic conditions (wobble board and antero-posterior / medio-lateral tilted platforms) during bipedal and one-legged stance. The COP velocity was registered at 100 Hz by means of posturography system FiTRO Sway check based on dynamometric platform. Subjects were instructed to minimize postural sway by standing as still as possible. Speed of step initiation and the soccer kick was measured using FiTRO Dyne Premium. Subjects were asked to either run-out or kick-off as fast as possible. The best result of three trials performed with injured and non-injured leg was taken for the evaluation.

Statistical analysis
Ordinary statistical methods including average and standard deviation were used. A Wilcoxon-test was employed to determine the statistical significance of differences between pre- and post-training values of sway variables registrated in static and dynamic conditions, speed of step initiation and the soccer kick, $p < 0.05$ was considered significant.

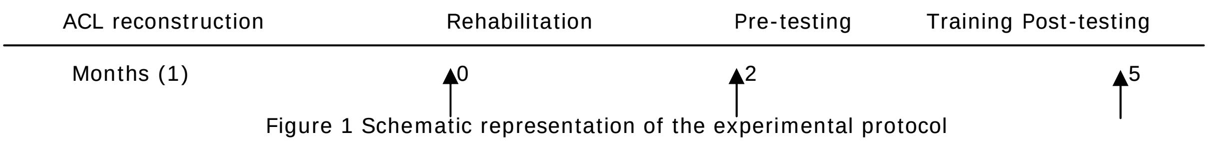
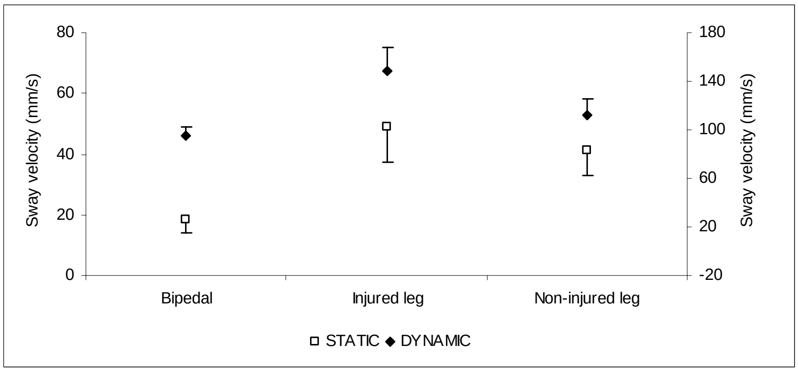


Figure 1 Schematic representation of the experimental protocol

Results



Pre-training measurements showed (Fig. 1) the non-injured-to-injured leg percent differences of 15.7% for static and 24.5% for dynamic balance. Figure 1 The COP velocity registered in static and dynamic conditions (wobble board) during bipedal and one-legged stance prior to training (after two months of conservative treatment). Following the training there were no changes in static balance on both legs (from 18.2 ± 3.3 mm/s to 15.8 ± 2.8 mm/s), on non-injured leg (from 41.3 ± 8.8 mm/s to 38.2 ± 7.8 mm/s), and on injured leg (from 49.0 ± 8.9 mm/s to 43.2 ± 7.7 mm/s) (Fig. 2). Likewise, the dynamic balance did not change while standing on both legs (from 95.2 ± 19.0 mm/s to 86.7 ± 17.8 mm/s) and on non-injured leg (from 112.3 ± 25.0 mm/s to 101.2 ± 21.8 mm/s), however a significant ($p \leq 0.01$) improvement on injured leg has been found (from 148.7 ± 22.8 mm/s to 118.0 ± 20.0 mm/s) (Fig. 3).

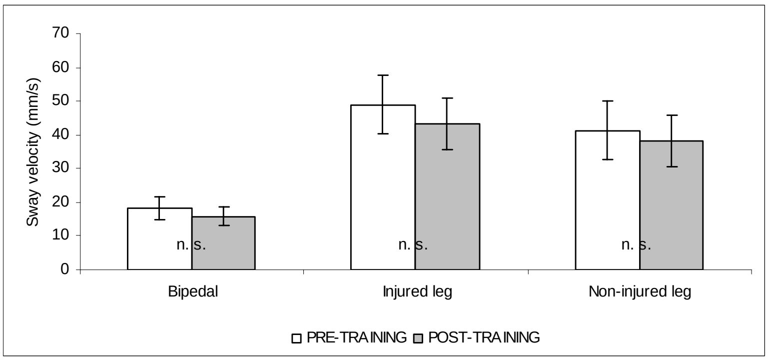


Figure 2 The COP velocity registered in static conditions during bipedal and one-legged stance prior to and after three months of instability resistance training

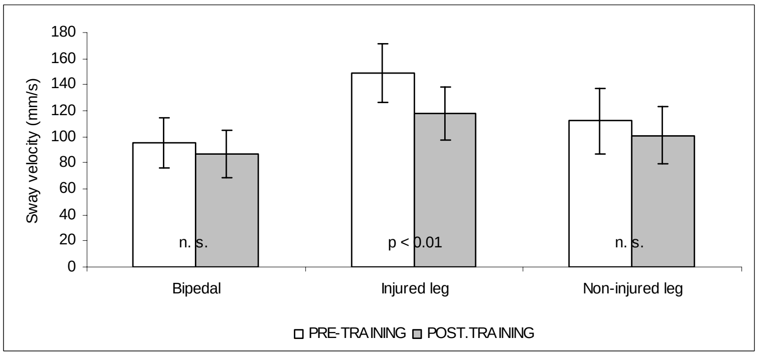


Figure 3 The COP velocity registered in dynamic conditions (wobble board) during bipedal and one-legged stance prior to and after three months of instability resistance training

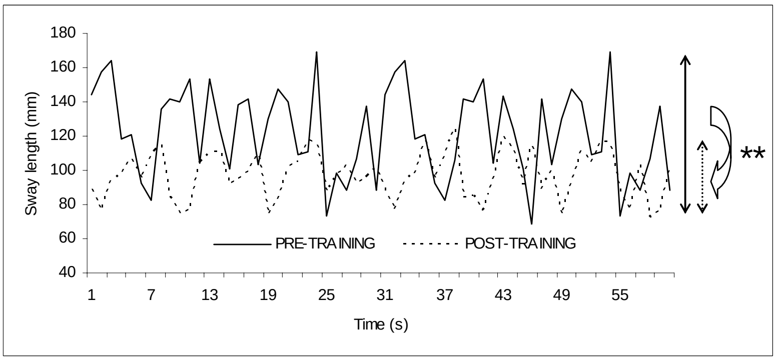


Figure 4 Kinetics of the COP velocity registered in dynamic conditions (wobble board) while standing on injured leg prior to and after three months of instability resistance training

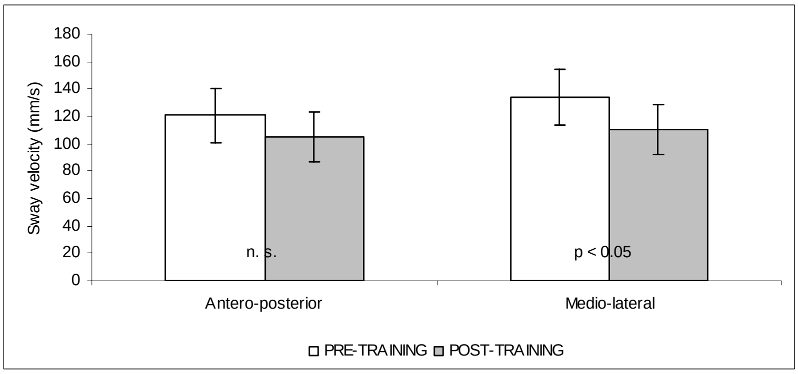


Figure 5 The COP velocity registered in dynamic conditions (antero-posterior / medio-lateral tilted platforms) during bipedal stance prior to and after three months of instability resistance training

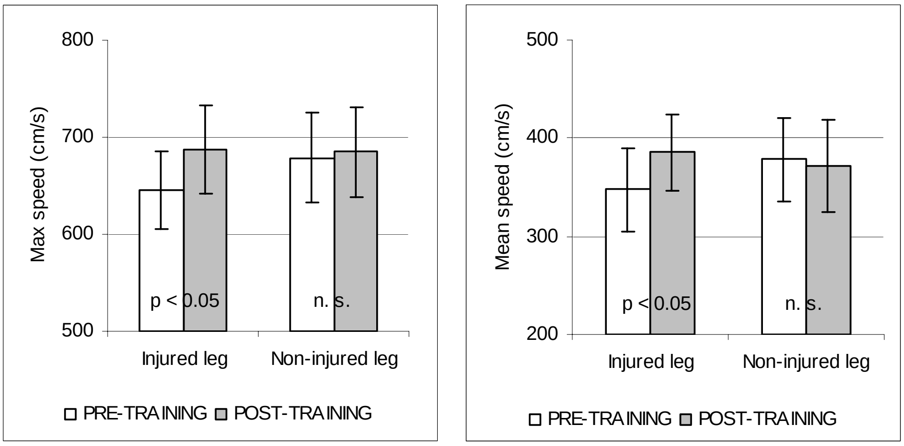


Figure 6 Max (a) and mean run-out speed (b) on injured and non-injured leg prior to and after three months of instability resistance training

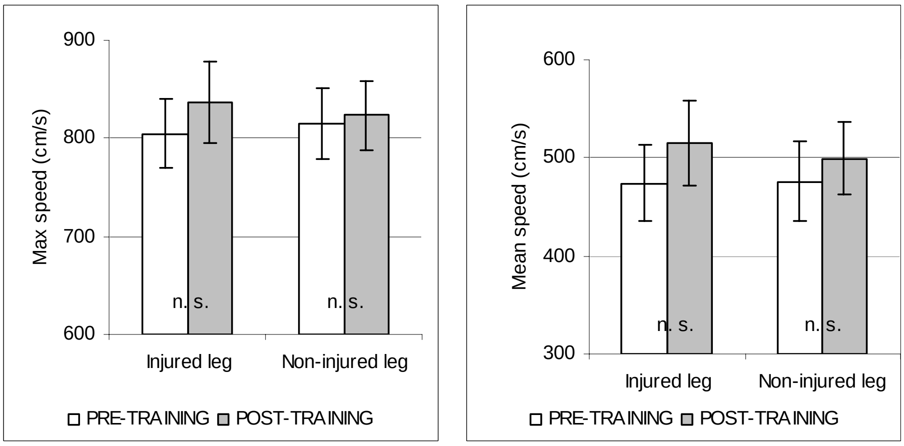


Figure 7 Max (a) and mean kick-off speed (b) on injured and non-injured leg prior to and after three months of instability resistance training

More specifically, the COP velocity not only decreased after training but also traversed on smaller amplitude (Fig.4). In addition, the COP velocity significantly ($p \leq 0.05$) decreased during bipedal stance on M-L tilted platform (from 134.2 ± 20.1 mm/s to 110.6 ± 18.2 mm/s) but not on those A-P tilted (from 120.6 ± 19.7 mm/s to 104.7 ± 18.0 mm/s) (Fig. 5). Furthermore, mean run-out speed significantly ($p \leq 0.05$) increased on injured leg (from 347.4 ± 42.3 cm/s to 385.3 ± 38.8 cm/s) but not on non-injured leg (from 378.1 ± 42.1 cm/s to 371.8 ± 47.1 cm/s) (Fig. 6). In contrast, no changes in mean kick-off speed on injured and non-injured leg have been found (from 474.0 ± 38.5 cm/s to 515.6 ± 43.3 cm/s and from 475.9 ± 40.7 cm/s to 499.5 ± 37.6 cm/s, respectively) (Fig. 7).

Discussion and conclusion

It has been found that even after 8-weeks of standard rehabilitation both static and dynamic balance was more profoundy impaired while standing on injured than on non-injured leg. This finding is in agreement with those of Holder-Powell and Rutherford (2000) who showed the long-term effect on balance after unilateral lower limb musculoskeletal injury. According to them full recovery is frequently not achieved and perhaps recovery does not continue to improve once the formal rehabilitation period is over. For this reason individuals used to continue in exercise program under supervision of professional instructor, as has been done in our study too.

Following 12-weeks of the instability resistance training applied, there were no improvement in static balance. This may be due insufficient specificity of static-testing conditions to reflect changes in postural stability after exercises predominantly performed on wobble boards. More specifically, the exercise program was designed close to the idea of Latash (2008) that rehabilitation strategies should be directed at optimizing function rather than at bringing movement patterns as close to „normal" as possible. In favour of this speak also our experience.

For instance, there is an overall agreement that higher COP velocity and area reflect impairment of postural stability, as has been seen in ACL-injured soccers in our study. In such a case, the rehabilitation is focused on improvement of balance with goal to see subject's upright posture more stable.

However, this assumed improvement of balance does not take into account the fact that this ability in most situations is integrated with other task (e.g., kicking a ball). From this point of view is important to focus the rehabilitation process on improvement of adaptability of postural control to new situations. In other words „to teach the body“ to be flexible and adaptable to perturbations so that balance is maintained. In doing so, examined individuals performed a wide variety of soccer skills on unstable platforms with aim to practice in high-demanding conditions on motor control.

According to the concept of training specificity (Sale, 1988), no crossover effects of such a functionally directed balance training on static balance measures can be assumed. On the other hand, greater stability on injured leg evaluated under dynamic conditions has been observed. In addition, sway velocity decreased during bipedal stance on medio-lateral tilted platform, suggesting more efficient utilization of hip strategy in postural control. Contrary to viscoelastic forces inherent to the ankle muscles that correct small perturbations of posture, for larger sway displacements, active contractions are required. These contractions could originate from stretch and vestibular reflexes, or be voluntary responses triggered by multimodal sensory inputs (Allum, 1983). It has been postulated (Allum & Honegger, 1998) that a confluence of trunk and upper-leg proprioceptive input establishes the basic timing of automatic, triggered balance corrections. While instability resistance training applied should certainly tax a proprioceptive control of posture, it has not been established whether any positive adjustments would be mediated through anticipatory postural adjustments (central processing).

The underlying neural adaptations occur at different sites of the central nervous system and the plasticity of the spinal, corticospinal and cortical pathways proved (Taube et al., 2008) to be highly task specific. So far, little is known about the plasticity of cerebellar and subcortical areas with regard to balance training because the difficulty in accessing these structures during postural tasks. Using transcranial magnetic stimulation Taube et al (2008) reported reduced cortical excitability following balance training, which was negatively correlated with changes in stance stability, i.e. subjects who reduced their cortical excitability to a greater extent showed greater improvements in stance stability. Conversely, when balance-trained subjects were measured in the voluntary task, enhanced cortical excitability was evident. These authors speculated that (synaptic) efficiency of direct corticospinal projections to the muscles encompassing the ankle joint increased by balance training and could be utilized in the voluntary contraction.

Since greater contribution of the motor cortex to voluntary movements like step initiation may be assumed, such adaptation might partly explain the increase in run-out speed on injured leg after training. However, combined Balance-strength exercises were insufficient stimuli to enhance speed of the kick-off. Similarly,

Aagaard et al (1996) found that even using different strength training regimes the kicking performance estimated by maximal ball flight velocity was unaffected. This may be ascribed to the fact that training program used could improve mainly feedback mechanisms. This assumption may be corroborated by findings of Kollmitzer et al (2000) who showed that motor-skill training including balance exercises increases the sensitivity of feedback pathways. However, during fast movements such as rapid kick a feedforward commands – in the absence of feedback – are used, and can even be used by central pattern generators to produce automatic behaviours. Therefore one may not expect substantial improvement of kicking performance without using specific soccer drills of appropriate intensity and duration.

Three months of instability resistance training including also soccer-specific drills improves balance under variety of dynamic conditions and speed of step initiation in athletes after ACL injury. However, such training is insufficient to enhance speed of the soccer kick. Therefore, more specific exercises should be implemented into training program in order to improve soccer-specific skills. Despite of this, resistance exercises performed on unstable surfaces represent an effective means for improvement of neuromuscular performance in athletes after lower limb injury.

References

Aagaard, P., Simonsen, E.B., Trolle, M., Bangsbo, J., & Klausen, K. (1996). Specificity of training velocity and training load on gains in isokinetic knee joint strength. *Acta Physiol Scand*, 156(2), 123-129.

Allun, J. (1983). Organization of stabilizing reflex responses in tibialis anterior muscles following ankle flexion perturbations of standing man. *Brain Res*, 264(2), 297-301.

Allum, J., & Honegger, F. (1998). Interactions between vestibular and proprioceptive inputs triggering and modulating human balance-correcting responses differ across muscles. *Exp Brain Res*, 121(4), 478-494.

Barrack, R.L., Skinner, H.B., & Buckley, S.L. (1989). Proprioception in the anterior cruciate deficient knee. *American Journal of Sports Medicine*, 17(1), 1-6.

Barret, D.S. (1991). Proprioception and function after anterior cruciate reconstruction. *Journal of Bone and Joint Surgery*, 73B(5), 833-837.

Corrigan, J.P., Willian, F.C., & Michael, P.B. (1992). Proprioception in the cruciate deficient knee. *Journal of Bone and Joint Surgery*, 74B(2), 247-250.

Fonseca, S.T., Ocarino, J.M., Silva, P.L.P., Guimaraes, R.B., Oliveira, M.C.T., & Lage, C.A. (2005). Proprioception in individuals with ACL-deficient knee and good muscular and functional performance. *Research in Sports Medicine*, 13, 47-61.

Friden, T., Roberts, D., Movin, T., & Wredmark, T. (1998). Function after anterior cruciate ligament injuries: Influence of visual control and proprioception. *Acta Orthopaedica Scandinavica*, 69(6), 590-594.

Good, L., Roos, H., Gottlieb, D.J., Reström, P.A., & Beynnon, B.D. (1999). Joint position sense is not changed after acute disruption of the anterior cruciate ligament. *Acta Orthopaedica Scandinavica*, 70(2), 194-198.

Holder-Powell, H.M., & Rutherford, O.M. (2000). Unilateral lower-limb musculoskeletal injury: its long-term effect on balance. *Arch Phys Med Rehabil*, 81(3), 265-268.

Kollmitzer, J., Ebenbichler, G., Sabo, A., Kerschan, K., & Bochdansky, T. (2000). Effects of back extensor strength training versus balance training on postural control. *Med Sci Sports Exerc*, 32(10), 1770-1776.

Latash, M.L. (2008). *Neurophysiological basis of movement*. Champaign, IL: Human Kinetics.

MacDonald, P.B., Hedden, D., Pacin, O., & Sutherland, K. (1996). Proprioception in anterior cruciate ligament-deficient and reconstructed knees. *Amer. Journal of Sports Medicine*, 24(6), 774-778.

Roberts, D., Friden, T., Zatterstrom, R., Lindstrand, A., & Moritz, U. (1999). Proprioception in people with anterior cruciate ligament-deficient knee: Comparison of symptomatic and asymptomatic. *Journal of Orthopaedic and Sports Physical Therapy*, 29(10), 587-594.

Sale, D.G. (1988). Neural adaptations to resistance training. *Medicine and Science in Sports and Exercise*, 20(5), S135-145.

Taube, W., Gruber, M., Gollhofer, A. (2008). Spinal and supraspinal adaptations associated with balance training and their functional relevance. *Acta Physiol*, 193(2), 101-116.

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EFEKT NESTABILNOG ISTRAJNOG TRENINGA NA NEUROMUSKULARNO DJELOVANJE KOD SPORTAŠA NAKON POVREDE ANTERIOR CRUCIATE LIGAMENTA

Sažetak

Studija vrednuje efekte na statičku i dinamičku ravnotežu, brzinu početnog pokreta pri koraku i fudbalskog šuta nakon treniranja otpora nestabilnosti kod sportaša nakon ACL povrede. Grupa od 14 fudbalera (god. 21.8±3.4y, visina 182.2±5.6cm, i težina 76.7±4,8kg) je prošla kombinaciju vježbi za otpornost i ravnotežu dva mjeseca nakon oporavka (u trajanju od 30 min) u toku 12 sedmica (4-5 puta sedmično). Posturalna stabilnost je procijenjena i statičkim i dinamičkim uslovima (ljuljajuća ploča i antero-posteriorne/medio-lateralne nakošene platforme) za vrijeme stajanja na obje i na jednoj nozi. COP brzina je zabilježena na 100Hz pomoću posturografskog sistema FiTRO Sway check koji je baziran na dinamometričkoj platformi. Brzina zakoračenja i fudbalskog šuta je mjerena pomoću Fitro Dyne Premiuma. Mjere prije trenažnog procesa su pokazale razlike od 15,7% za statičku i 24,5% za dinamičku ravnotežu kod povrijeđene i nepovrijeđene noge. Tokom treninga nije bilo promijena kod statičke ravnoteže na obje noge (od 18.2 ± 3.3 mm/s do 15.8 ± 2.8 mm/s), na zdravoj nozi (od 41.3 ± 8.8 mm/s do 38.2 ± 7.8 mm/s), a na povrijeđenoj nozi (od 49.0 ± 8.9 mm/s do 43.2 ± 7.7 mm/s). Također, dinamička ravnoteža se nije promijenila pri stajanju na obje noge (od 95.2 ± 19.0 mm/s do 86.7 ± 17.8 mm/s) i na zdravoj nozi (od 112.3 ± 25.0 mm/s do 101.2 ± 21.8 mm/s); ali značajan napredak ($p \leq 0.01$) je zabilježen na povrijeđenoj nozi (od148.7 ± 22.8 mm/s do 118.0 ± 20.0 mm/s). COP brzina se znatno smanjila ($p \leq 0.05$) za vrijeme stajanja na obje noge na M-L kosoj platformi (od 134.2 ± 20.1 mm/s do 110.6 ± 18.2 mm/s) ali na na A-P kosoj platformi (od 120.6 ± 19.7 mm/s do 104.7 ± 18.0 mm/s). Brzina istrčavanja se značajno povećala na povrijeđenoj nozi, ali ne na zdravoj nozi. Pa ipak, nije bilo promjena u brzini ispucavanja na zdravoj i povrijeđenoj nozi. Možemo zaključiti da vježbe ze otpornost izvođene na nestabilnoj površini predstavljaju efektno sredstvo za unaprijeđenje dinamičke ravnoteže pod različitim okolnostima i brzine zakoračenja kod sportaša nakon ACL povrede. Pa ipak, konkretnije vježbe bi se trebale koristiti pri treningu za poboljšanje specifičnih vještina, poput brzine ispucavanja.

Ključne riječi*: sportaši, povreda ACL, nestabilni trening izdržljivosti*

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