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The role of the pelvic and thigh muscles in joint stabilization and performance in unilateral jumps

PhD thesis

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INTRODUCTION

The number of lower limb injuries resulting from joint instability during ground-based sports activities has increased dramatically in recent decades. This may be due to a number of reasons such as increased performance demands in sports, higher workloads and reduced recovery time for athletes, or a lack of versatile skill development resulting from early specialisation. The treatment of injuries resulting from joint instability, which very often have serious outcomes, places a huge financial burden on the health care system, and the chances of athletes returning to sport at full fitness are minimal. Exploring the causes and mechanisms of joint instability is a young field of research in biomechanics. Human movements are very complex, the execution of a movement is the result of the activity of many muscles acting together in a precisely controlled and timed manner. As a result, in order to elucidate movements as accurately as possible, research has to take an increasing number of parameters into account when trying to quantify the stability of one or more joints at a time. It is also crucial to study conditions resulting from previous injuries and deconditioning, such as joint instability, so that situations that are dangerous to health can be more easily avoided.

During the performance of sporting activities (training, matches, competition, etc.), the most common injuries that can occur are related to the degree of knee joint instability, with the knee joint being the main site of injury (Shultz et al., 2004). The majority of knee injuries occur most often during the execution of jumps, reaches, changes of direction, lunges or lateral rotations during running. An important issue for research is how to reduce the number of sports injuries and what preventive methods can be used to avoid potential injuries. In some cases, these injuries can lead to permanent or irreversible damage.

In many cases, the degree of risk of injury depends on the nature of the activity itself, but it is also significantly influenced by the fitness level of the athlete (Taimela et al., 1990). Deficiencies detected early can be treated before problems occur, and corrected by appropriate training, therapy and exercises. Many researchers are concerned with the question of how to achieve greater performance and strength in the execution of movements, and which muscle groups can be activated to achieve better results. It is also important to identify the movement patterns that maximise performance in sports movements and to determine whether joint instability is related to performance and what impact it has on performance during movement. It is also important to identify which muscle groups have the greatest influence on joint stability.

The results of our studies may be of great help in future effective training planning and may also contribute to the prevention of knee injuries.

AIMS

The aim of our investigations was to determine the neuromechanical mechanisms involved in the stabilization of the knee joint, pelvic and lumbar spine during unilateral jumping. In addition, we further aimed to determine the extent to which the maximal strength of each thigh and pelvic girdle muscle influences the success of unilateral jumps.

Based on this, the following hypotheses were formulated and tested in two separate studies.

Hypotheses of study 1:

1. Gluteus medius (GM), erector spinae (ES) és quadratus lumborum (QL) activation and maximal voluntary hip joint abduction isometric force are related to the degree of pelvic tilt during unilateral countermovement jump (CMJ).

2. maximum voluntary hip joint abduction isometric force and GM activity during unilateral CMJ are related to the degree of dynamic knee valgus (DKV) in the knee joint.

3. The magnitude of electromyography (EMG) activity measured during unilateral CMJ but normalized to EMG activity during maximal isometric force differs in the muscles studied.

4. The maximum voluntary hip joint abduction isometric force is related to the propulsive impulse measured during unilateral CMJ.

Hypotheses of Study 2:

1. propulsion impulse measured during unilateral CMJ is related to the maximum voluntary torque of the knee extensor and knee flexor muscles and the maximum voluntary hip joint abduction isometric force.

2. The magnitude of the correlations examined above are statistically different.

MATERIALS AND METHODS

Frontal plane knee and pelvic stabilizing mechanisms of pelvic muscles during unilateral jumps

Participants

Twenty-five healthy, athletic male students were included (age: 21.2 ± 1.3 years, height: 182.4 ± 7.3 cm, weight: 76.5 ± 10 kg, years of training: 9.7 ± 2.6 years). Subjects participated in private sport training on average 2.9 times per week in the following sports: athletics, football, basketball, swimming, martial arts, triathlon, dance, in addition to the practical courses in the curriculum. None of them were national team or elite athletes at the time of the study. The inclusion criterion was that the subjects had at least one year of pylometric training experience. Exclusion criteria were any acute or chronic spine, pelvic girdle or knee injury, pain or previous surgery.

Experimental protocol

To prepare for the measurements, subjects began with a five-minute cycle ergometric warm-up at an arbitrary speed. This was followed by a stretching gymnastics routine at an individual pace and intensity, warming up the subjects' muscles, primarily in the trunk and lower limbs. Following the warm-up, the force capacity and EMG activity of the subject muscles were assessed using a dynamometer with maximal voluntary isometric contractions (MVC), followed by unilateral jump-up tests. During the jump-up tests, in addition to the EMG activity of the tested muscles, the kinematics of the knee joint and pelvis were also measured using motion tracking sensors synchronized with the EMG.

Electromyography

Bipolar surface Ag/AgCl electrodes were applied to the ES and QL on the opposite side of the subjects' jumper leg and to the GM on the side of the jumper leg to perform EMG measurements. Sensors for the electrodes were also attached to the skin surface and all electrical signals measured during MVC and jump-up tests were telemetrically transmitted from the sensors to the amplifier (Noraxon, Scottsdale, USA, sampling frequency 2000 Hz). For all muscles, the peak of EMG activity was considered for data analysis.

MVC tests and unilateral jump test

The MVC tests were used to determine the maximum voluntary EMG activity of the tested muscles during isometric contraction, to which the EMG values measured during the jump-up tests were normalized. To determine the maximal EMG activity of the unilateral ES and QL of the leg (jumping leg) performing the unilateral jump tests, subjects were positioned in lateral recumbency and performed trunk lateral flexion with maximal force.

The second MVC test was the hip joint abduction, where the maximum EMG activity of the GM was measured on the side corresponding to the hock. Here, the subjects were also in lateral position, with the test leg moved away from the ground with maximum force and counter-weight. For this test, peak hip joint abductor forces were also measured using a hand-held dynamometer. For both MVC tests, two submaximal warm-up trials were followed by two maximal force trials, with two minutes rest between repetitions.

Following the MVC tests, subjects performed a unilateral CMJ test with the dominant limb standing on the force plate. The jump-up was to be performed with a hip hold and the only instruction was that subjects should aim for the highest possible jump-up. Two trials and three repetitions at maximum strength were performed, with a one-minute rest between repetitions.

Data and statistical analysis

Ground reaction force recorded using a force plate was determined as a function of time, and propulsive impulse, a quantitative measure of jumping ability, was calculated and normalised to the subject's body weight in kilograms. All measured kinematic and EMG data were synchronized and processed using myoResearch 3.18 software. All unilateral CMJ EMG data were normalized to the EMG activity values during hip joint abduction MVC or trunk lateral flexion MVC. For statistical analyses, mean, standard deviation, one-way analysis of variance (ANOVA), Shapiro-Wilk normality test and Pearson's correlation coefficient were calculated. Statistical significance was established at $p \leq 0.05$.

The effect of the thigh muscles and hip abductors maximal strength on the jump performance in unilateral jumps

Participants

Twenty-five healthy male university students majoring in physical education (age: 20.4 ± 1.9 years, weight: 78.6 ± 7.7 kg, height: 182.7 ± 5.6 cm) participated in the study. Exclusion criteria were any acute or chronic spinal, pelvic girdle or knee injury, pain, or previous surgery, or acute pain from an orthopaedic disorder that could have prevented the participant from maximal lower limb strength training.

Experimental protocol

On the day of the study, subjects began their preparation for the measurements with a five-minute cycle ergometric warm-up at an arbitrary speed. This was followed by stretching exercises at an individual pace and intensity, with subjects warming up primarily the trunk and lower limb muscles. This was followed by MVC measurements at knee joint extension, knee joint flexion and hip joint abduction. Unilateral CMJ-type vertical jumps were then performed with the subjects. For each subject, only the dominant leg was tested.

MVC tests and unilateral jump test

A Multicont II type computer-controlled dynamometer was used to determine the maximum force capacity of the knee extensors and knee flexors. Subjects performed MVC knee extension at 70 degrees knee joint angle and MVC knee flexion at 20 degrees knee joint angle. The maximum torques were determined for both MVC tests above. The MVC test for hip joint abduction was the same as described for the first test. For all MVC tests, subjects performed three repetitions with a two-minute rest period between each repetition.

Following the MVC tests, subjects performed a unilateral CMJ test with the dominant limb standing on the force plate. The test procedure was the same as described for the first test.

Data and statistical analysis

For data processing, the propulsive impulse was determined as described in the previous study. The statistical analysis was performed in a similar way, but we also used Fisher's exact test to determine the correlations between the data. Statistical significance was determined at $p \leq 0.05$.

RESULTS

Frontal plane knee and pelvic stabilizing mechanisms of pelvic muscles during unilateral jumps

In the first study, the ES showed the highest normalized activity during unilateral CMJ, with significant differences between ES and GM and ES and QL.

Pearson's correlation results show that DKV was not correlated with hip joint abductor strength, but was negatively correlated with GM activity during unilateral CMJ. Thus, we can state that the higher the relative activity of the GM, the lower the DKV will be.

This correlation became stronger when we examined the relationship between the DTV and the GM activity/hip joint abduction ratio during unilateral CMJ. Thus, high abduction force alone is not sufficient, the GM must be activated sufficiently during unilateral upstroke to reduce the rate of DKV.

Table 1 illustrates the correlation coefficients between all why and calculated neurokinematic and kinetic variables. The correlation calculations show that pelvic tilt was not correlated with muscle strength of the hip joint abductors and no muscle activity during unilateral CMJ. The unilateral CMJ propulsive impulse correlated with both ES and QL activity ($p < 0.05$), but did not correlate with GM activity, pelvic tilt or DKV.

Table 1: Pearson's correlation coefficients and Spearman's rank correlations between neurokinematic and kinetic data (n = 25).

	I	DKV	PT	F_{abd}	EMG GM/F_{abd}	EMG GM	EMG ES
DKV	0,01						
PT	0,10	0,31					
F_{abd}	0,16	0,46	-0,33				
EMG GM/F_{abd}	-0,07	-0,71*	-0,23	-0,17			
EMG GM	0,13	-0,44*	-0,10	0,10	0,85		

EMG ES	0,43*	-0,25	-0,13	-0,04	0,36	0,45*	
EMG QL	0,42*	0,00	-0,13	0,12	-0,14	0,11	0,46*

I = propulsion impulse; DKV = dynamic knee valgus; PT = pelvic tilt; F_{abd} = hip joint abductor strength; EMG GM/F_{abd} = relative gluteus medius muscle activity/hip joint abductor strength ratio; GM = gluteus medius normalized muscle activity; ES = erector spinae normalized muscle activity; QL = quadratus lumborum normalized muscle activity; *Significance level $p < 0.05$.

The effect of the thigh muscles and hip abductors maximal strength on the jump performance in unilateral jumps

The results of our second study are shown in Table 2. We find that the propulsive impulse correlates with both the peak torque of the knee extensors and flexors and the maximum force of the hip abductors.

*Table 2: Pearson correlation coefficients for the dynamic variables (n = 25). *Significant $p \leq 0.05$ **Significant $p \leq 0.005$.*

	I	M_{ext}	M_{flex}
M_{ext}	$0,51^{**}$		
M_{flex}	$0,48^{*}$	$0,59^{**}$	
F_{abd}	$0,63^{**}$	0,23	0,33

I = propulsive impulse; M_{ext} = peak torque of knee joint extensors; M_{flex} = peak torque of knee joint flexors; F_{abd} = maximum force of hip joint abductors.

Examining which muscle groups shows the strongest correlation between torque or force and propulsive impulse, we found that there is no difference (Table 3). Both the torque of the knee extensors and flexors, and the strength of the hip joint abductors have the same effect on the propulsive impulse.

Table 3: Fisher exact test for propulsion impulse (n = 25)

	j = I k = M_{ext} h = M_{flex}	j = I k = M_{ext} h = F_{abd}	j = I k = M_{flex} h = F_{abd}
rjk	0,51	0,51	0,48
rjh	0,48	0,63	0,63
rkh	0,59	0,23	0,33

p	0,42	0,26	0,21

I = propulsive impulse; M_{ext} = peak torque of knee joint extensors; M_{flex} = peak torque of knee joint flexors; F_{abd} = maximum force of hip joint abductors; rjk and rjh = correlation coefficients of the two variables to be compared; rkh = correlation coefficient of the non-common variables; p = significance value.

DISCUSSION

The main findings of the first study were that subjects with higher DKV showed lower GM activity and that the degree of pelvic tilt was independent of ES or QL activation during unilateral CMJ. Furthermore, our data indicate that hip joint abductor strength alone did not control the degree of DKV during unilateral CMJ. Finally, the unilateral CMJ propulsive impulse did not correlate with either DKV or pelvic tilt.

Although there was no significant correlation between maximum hip joint abductor force and DKV, in our study, GM activity and GM activity/hip joint abduction ratio measured during unilateral CMJ were negatively correlated with the degree of DKV. These correlations suggest that it is probably not the maximal strength of the hip joint abductors but the activity of the hip joint abductor muscle (GM) that is the variable that plays a major role in the development of DKV in the study group of young, trained men.

The QL has a role as an accessory muscle in the movement of the ribs and contributes to the stabilization and movement of the spine and pelvis (Bordoni & Varacallo, 2022). The ES stabilizes the spine in the sagittal plane (Studnicka & Ampat, 2023) The GM also stabilizes the pelvis, in addition to preventing pelvic tilt (Shah & Bordoni, 2022). The GM and QL control pelvic tilt during unilateral movements (Oliver & Keeley, 2010). Since we did not find a correlation between ES, QL and pelvic frontal plane tilt, we conclude that other muscles such as the multifidus and/or transversus abdominis muscles may control pelvic frontal plane tilt.

Propulsive impulse was not correlated with the degree of DKV, pelvic tilt, and hip joint abductor strength during unilateral CMJ on the force plate. However, in our second study, we showed that subjects with greater hip joint abductor strength produced greater unilateral CMJ propulsive impulses, in contrast to the results of the first study. We observed that subjects in the first study had different magnitudes of hip joint abductor force compared to subjects in the latter study. For this parameter, we obtained a 25% higher value in the first study. The average DKV in our first study was only 6 degrees. If we had tested subjects with high DKV measures, it is assumed that this would have already affected unilateral CMJ performance. In our second study, we did not measure segmental kinematics, so there we do not have data on the extent of DKV during unilateral CMJ.

In the second study, we were able to confirm that, in addition to the role of the extensor and flexor muscles, which have been extensively studied, the hip joint abductors also play an important role in the increase in propulsive impulse of unilateral jumps. However, we found no difference in which variable is most associated with unilateral CMJ impulse. The effect of knee joint extensor strength on vertical jump performance is well known (Loturco et al., 2018). The role of knee joint flexors in jumping movements is more limited to stabilizing the knee joint (Porrati-Paladino & Cuesta-Barriuso, 2021), but strengthening exercises targeting the hamstring muscles can improve jumping performance (Hoyo et al., 2015).

In summary, the present studies provide evidence that hip joint abductors are indirect frontal plane stabilizers of the knee by reducing DKV and joint loading. We found that it is not the maximum force of the hip joint abductors but rather the activity of the GM that controls DKV. Furthermore, we conclude that the maximum muscle strength of the hip joint abductors contributes to the unilateral jump vertical jump performance. Several studies have demonstrated the effect of training the hamstring abductor muscles to reduce the risk of knee injury (Dyk et al., 2019), however, strengthening the hip joint abductor muscles is also widely recommended for athletes to ensure primary ACL protection, especially in athletes in sports where unilateral jumps and landings are performed in unexpected situations. Understanding the protective behaviour of the hamstring muscles is very important in the prevention of ACL tears. Therefore, future research investigating age-specific activation of the hamstring flexor muscles in relation to GM activation and frontal plane knee kinematics may be useful. Health and fitness status and the effect of gender also need to be studied.

REFERENCES

Bordoni, B., & Varacallo, M. (2022). Anatomy, Abdomen and Pelvis, Quadratus Lumborum. In *StatPearls*. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK535407/

Dyk, N. van, Behan, F. P., & Whiteley, R. (2019). Including the Nordic hamstring exercise in injury prevention programmes halves the rate of hamstring injuries: A systematic review and meta-analysis of 8459 athletes. *British Journal of Sports Medicine*, *53*(21), 1362–1370. https://doi.org/10.1136/bjsports-2018-100045

Hoyo, M. de, Pozzo, M., Sañudo, B., Carrasco, L., Gonzalo-Skok, O., Domínguez-Cobo, S., & Morán-Camacho, E. (2015). Effects of a 10-Week In-Season Eccentric-Overload Training Program on Muscle-Injury Prevention and Performance in Junior Elite Soccer Players. *International Journal of Sports Physiology and Performance*, *10*(1), 46–52. https://doi.org/10.1123/ijspp.2013-0547

Loturco, I., Pereira, L. A., Kobal, R., Abad, C. C. C., Komatsu, W., Cunha, R., Arliani, G., Ejnisman, B., Pochini, A. de C., Nakamura, F. Y., & Cohen, M. (2018). Functional

Screening Tests: Interrelationships and Ability to Predict Vertical Jump Performance. *International Journal of Sports Medicine*, *39*(3), 189–197. https://doi.org/10.1055/s-0043-122738

Oliver, G. D., & Keeley, D. W. (2010). Gluteal Muscle Group Activation and its Relationship With Pelvis and Torso Kinematics in High-School Baseball Pitchers. *The Journal of Strength & Conditioning Research*, *24*(11), 3015–3022. https://doi.org/10.1519/JSC.0b013e3181c865ce

Porrati-Paladino, G., & Cuesta-Barriuso, R. (2021). Effectiveness of Plyometric and Eccentric Exercise for Jumping and Stability in Female Soccer Players—A Single-Blind, Randomized Controlled Pilot Study. *International Journal of Environmental Research and Public Health*, *18*(1), Article 1. https://doi.org/10.3390/ijerph18010294

Shah, A., & Bordoni, B. (2022). Anatomy, Bony Pelvis and Lower Limb, Gluteus Medius Muscle. In *StatPearls*. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK557509/

Shultz, S. J., Carcia, C. R., & Perrin, D. H. (2004). Knee joint laxity affects muscle activation patterns in the healthy knee. *Journal of Electromyography and Kinesiology*, *14*(4), 475–483. https://doi.org/10.1016/j.jelekin.2003.11.001

Studnicka, K., & Ampat, G. (2023). Lumbar Stabilization. In *StatPearls*. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK562179/

Taimela, S., Kujala, U. M., & Osterman, K. (1990). Intrinsic Risk Factors and Athletic Injuries. *Sports Medicine*, *9*(4), 205–215. https://doi.org/10.2165/00007256-199009040-00002

PUBLICATIONS

Publications related to the thesis topic:

Sebesi B, Fésüs Á, Varga M, Atlasz T, **Vadász K,** Mayer P, Vass L, Meszler B Balázs B, Váczi M. (2021) The Indirect Role of Gluteus Medius Muscle in Knee Joint Stability during Unilateral Vertical Jump and Landing on Unstable Surface in Young Trained Males APPLIED SCIENCES-BASEL (2076-3417): 11 16 Paper: 7421. 10 p. (**Q2; IF: 2,838**)

Vadász K, Varga M, Sebesi B, Hortobágyi T, Murlasits Zs, Atlasz T, Fésüs Á, Váczi M. (2023) Frontal Plane Neurokinematic Mechanisms Stabilizing the Knee and the Pelvis during Unilateral Countermovement Jump in Young Trained Males INTERNATIONAL JOURNAL OF ENVIRONMENTAL RESEARCH AND PUBLIC HEALTH 20 : 1 Paper: 220 (**Q2; IF: 4,614**)

Presentation related to the thesis topic:

Varga M, Nyisztorné Mayer P, Vass L, **Vadász K,** Sebesi B, Meszler B, Atlasz T, Váczi M. (2018) Térdízületi és medencestabilizáció frontális síkú neurokinematikai mechanizmusai unilateralis felugrásnál MAGYAR SPORTTUDOMÁNYI SZEMLE 19 : 77(5) pp. 78-78. , 1 p.

Sebesi B, Mayer P, Vass L, **Vadász K,** Varga M, Meszler B, Atlasz T, Váczi M. (2018) The role of hip joint abductors in stabilizing the knee joint during unilateral jumping and unilateral landing on unstable surface Megjelenés:

Sebesi B, Nyisztorné Mayer P, Vass L, **Vadász K,** Varga M, Meszler B, Atlasz T, Váczi M. (2018) Térdízületi stabilizáció unilaterális felugrásnál és instabil leérkezésnél Konferencia helye, ideje: Budapest, Magyarország 2018.12.07. - 2018.12.08. Budapest: Magyar Sporttudományi Társaság,

Sebesi B, Mayer P, Vass L, **Vadász K,** Varga M, Meszler B, Atlasz T, Váczi M. (2019) The role of gluteus medius muscle in stabilizing the knee joint during jumping and landing on unstable surface In: Proceedings of Global Congress on Physiotherapy, Physical rehabilitation & Sports Medicine 2019-04-22-24. [Dubai, Egyesült Arab Emírségek] pp. 55-55. , 1 p.

Varga M, Atlasz T, **Vadász K**, Vass L, Meszler B, Mayer P, Sebesi B, Váczi M. (2019) Frontal plane neurokinematical mechanisms of knee joint and pelvis stabilization during unilateral vertical jump In: Proceedings of Global Congress on Physiotherapy, Physical rehabilitation & Sports Medicine 2019-04-22-24. [Dubai, Egyesült Arab Emírségek] pp. 56-56. , 1 p.

Sebesi B, Nyisztorné Mayer P, Vass L, **Vadász K**, Varga M, Meszler B, Atlasz T, Váczi M. (2019) The role of hip joint abductors in stabilizing the knee joint during unilateral jumping and unilateral landing on unstable surface In: Csiszár, Beáta; Bódog, Ferenc (szerk.) Medical Conference for PhD Students and Experts of Clinical Sciences : Book of abstracts Pécs, Magyarország : Pécsi Tudományegyetem Doktorandusz Önkormányzat, 87 p. p. 25

Vadász K, Nyisztorné Mayer P, Vass L, Varga M, Sebesi B, Meszler B, Atlasz T, Váczi M. (2019) Medenceövi izmok aktivitása unilaterális felugrásnál In: IV. Sporttudományi PhD Szimpózium : Program- és absztrakfüzet p. 58 , 58 p.

Sebesi B, Nyisztorné Mayer P, Vass L, **Vadász K,** Varga M, Meszler B, Atlasz T, Váczi M. (2020) A térdízület direkt és indirekt stabilizációjának biomechanikai vizsgálata = Direct and indirect stabilization mechanisms in the knee joint In: Prisztóka, Gyöngyvér; Pfefferkorn, Laura-Jane; Kertai, Bendegúz (szerk.) XVIII. Szentágothai János Multidiszciplináris Konferencia és Hallgatói Verseny Absztrakt kötet XVIII. János Szentágothai Multidisciplinary Conference and Student Competition Book of Abstracts Pécs, Magyarország : János Szentágothai Scholastic Honorary Society, Faculty of Sciences, University of Pécs 187 p. pp. 173-174. , 2 p.

Varga M, Atlasz T, **Vadász K,** Vass L, Meszler B, Mayer P, Sebesi B, Váczi M. (2020) Összefüggés a gluteus medius aktivitása és a térd valgus között unilaterális felugrással = Association between gluteus medius activity and knee valgus during unilateral vertical jump In: Prisztóka, Gyöngyvér; Pfefferkorn, Laura-Jane; Kertai, Bendegúz (szerk.) XVIII. Szentágothai János Multidiszciplináris Konferencia és Hallgatói Verseny Absztrakt kötet XVIII. János Szentágothai Multidisciplinary Conference and Student Competition Book of Abstracts Pécs: János Szentágothai Scholastic Honorary Society, Faculty of Sciences, University of Pécs 187p. pp 175-177. , 2 p.

Vadász K, Nyisztorné Mayer P, Varga M, Sebesi B, Váczi M. (2021) Medenceövi izmokban mért neurokinematikai mechanizmusok unilaterális felugrásnál MAGYAR SPORTTUDOMÁNYI SZEMLE 22. : 91(3) pp. 121-121. , 1 p.

Sebesi B, Varga M, Fésüs Á, Ivusza P, Gáspár B, **Vadász K,** Váczi M. (2022) A medence frontális síkban történő elmozdulásának hatása az unilaterális felugrási teljesítményre és a térdízületi stabilizációra = Effect of frontal plane pelvic tilt on unilateral jump performance and knee joint stabilization In: Prisztóka, Gyöngyvér; Kertai, Bendegúz (szerk.) XX. Szentágothai János Mutidiszciplináris Konferencia és Hallgatói Verseny Absztrakt kötet / XX. János Szentágothai Multidisciplinary Conference and Student Competition Book of Abstracts Pécs, Magyarország : PTE TTK Szentágothai János Szakkollégium, Tehetségpont és Egyesület 295 p. pp. 283-284. , 2 p.