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Original Article

Determination of lower quarter dynamic balance in healthy adults

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Abstract:
Purpose: - To study the dynamic balance of lower extremities and to measure the proprioceptive force sense (FS) in healthy, untrained man (n=15) and women (n=15), ages 30–50 years; - To check sex differences, leg differences and to study the correlation among proprioception and balance. **Methodology:** The anthropometric parameters were evaluated by bioimpedance analyzer. The dynamic balance was measured by the Y Balance Test –Low Quarter (YBT-LQ) with a system - Y Balance Test Kit, FMS, on the dominant and non-dominant leg (or reaching and stance leg), in anterior-(ANT), posteromedial-(PM) and posterolateral-(PL) direction. The composite score (CS) was calculated as a criterion for bilateral symmetry. The maximal isometric torque and FS protocol, were performed with isokinetic system (Biodex 4 Pro). The participants reproduced 50% of the peak torque of quadriceps femoris during the FS measurement. The assessment of FS was based on the calculation of the absolute error (AE) in percentages. All parameters and the values of AE, are presented as means ± SD. For the statistical significance of the differences between means ($p<0.05$), the test of Mann-Whitney, Kruskal-Wallis ANOVA test, and Dunn's post hoc test, were applied. The Pearson coefficient was used to asses correlations ($p<0.05$). **Results:** There was no significant difference between the dominant and non-dominant leg in both sexes which shows good bilateral symmetry in male and female in all directions, where the values of CS>95 %. There was a significant difference between men and women, concerning the values for the dynamic balance in PM and PL directions for dominant and non-dominant leg; for men the values were higher ($p<0.05$) as compared with those for women. Moderate negative correlations ($r=- 0.68$; $p=0.005$) between AE and the YTB-LQ values for ANT direction of the both legs, were obtained only in female. **Conclusion:** Establishing bilateral symmetry in ANT, PM and PL directions in male and female with YTB-LQ, should be considered as important attribute in assessing dynamic balance in healthy untrained. The significant differences ($p<0.05$) between the sexes in YTB-LQ in the PM and PL directions were found, which show better levels of dynamic balance in men. The moderate negative correlations found in female, between the values of YTB-LQ in ANT direction and AE, suggest that the FS of the quadriceps muscle of the stance leg is reduced earlier in women, while in men it persists.
Key Words: **- Y balance test lower quarter (YBT-LQ), force sense (FS), males/females, dynamic balance,**

Introduction

Balance, also known as "postural control", can be defined statically as the ability to maintain a certain position and dynamically as the ability to perform a certain task and at the same time maintain a stable position (Lee et al., 2015) at low amplitude postural fluctuations. Postural control involves the coordination and integration of multiple sensory and motor elements. Sensory information about the body's position in space (including visual, vestibular, proprioceptive, and tactile) is received and integrated by the brain, resulting in appropriate sensomotor responses to maintain balance (Rasman et al., 2018). Feedback and reorientation mechanisms play a vital role in controlling movement and performing various motor tasks. As a result, there is growing interest in testing and evaluating dynamic stability (Freund et al., 2018; Plisky et al., 2021; Alnahdi et al., 2015; Neji et al., 2020). Stimulation of mechanoreceptors located in the periphery (i.e., skin, ligaments, muscles, and joints) provides afferent feedback through the spinal pathways regarding mobility and position in different segments of the body during movement (Riemann and Lephart, 2002). The motoneuron activation pattern is fine-tuned by feedback from those mechanoreceptors that act either monosynaptically or through inhibitory interneurons and provide a corrective response to action. Sensor inputs are needed to detect unstable conditions (i.e., disturbances in the system), while motor responses are vital for initiating timely and appropriate responses to counteract these disturbances (Rasman et al., 2018). Studies show that static and dynamic balance deficits are common in individuals with a history of ankle sprains, chronic ankle instability (Bressel et al., 2007, Grueva-Pancheva, 2021), anterior cruciate ligament injury, anterior knee pain (Shaffer et al., 2013), and pain in the lower back observed in both untrained individuals and athletes (Avramova M., 2021). Studies report age-related changes in women, demonstrating significantly reduced flexors and extensor strength of the lower

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extremities and balance (Lee et al., 2015), but there is no data comparing healthy untrained men and women and reporting specific sex differences. Muscle force is also a fundamental component affecting human movement performance. Little attention has been paid to the proprioceptive system, which ensures receptor signaling and participates in the control of force production. The information on the force sense (FS) in healthy people and the possible sex- and age-related differences is scarce and contradictory. This also concerns the extensors of the knee joint, which have a key role in the standing upright position of the body, locomotion, sports activities, etc (Tsvetkova-Gaberska, Pencheva 2019).

Another way to measure and evaluate dynamic balance and motor control is through the use of Y Balance Test- Lower Quarter (YBT-LQ). The YTB-LQ is a reliable and screening tool for identifying people with balance disorders and those at risk of lower limb injuries. It is also used to assess post-traumatic conditions and monitor rehabilitation progress. It is used for measuring dynamic balance and can be used to predict and cause damage in the presence of muscle imbalance. It is used to assess the balance of various types of sports injuries (Robert, 2013; Neji et al., 2020; Plisky et al., 2021), orthopedic (Grueva-Pancheva, 2021) and neurological disorders, and others. It serves as a tool for determining and assessing the risk of musculoskeletal injuries due to disturbed dynamic balance, both in clinical practice and in research. Nervous system training programs through targeted work to balance YBT-LQ have been reported to be extremely reliable and widely applicable in practice (Plisky et al., 2021). During performing YBT-LQ, the subject balanced on one leg while reaching as far as possible with the other leg in three directions. Therefore, this test measures strength, stability, and balance in different directions. The total YBT-LQ score is calculated by summing the three directions of reaching and normalizing the results to the length of the lower limb, while asymmetry is the difference between the volume of movement in centimeters between the right and left leg. The relationship between the FS of the quadriceps femoris, which is responsible for the dynamic balance to a greater extent than the hamstring muscles (Celenk et al., 2015), is of interest to prove, as well as the ability to reach the subject in different directions, and whether there are observed sex differences in this capacity.

It is known that with age, changes in the musculoskeletal system occur, with injuries to the lower extremities often associated with disturbances in the balance, gait, and overall function of the limbs. This more often affects the female sex (Freund et al., 2018; Nagasawa et al., 2010). However, there is no data in the literature on values for healthy untrained men and women in the middle-age (30–50 years), as well as the possible sex differences to help prevent the consequences of disorders in dynamic balance. Based on these data, the aims of the present study are: to measure and compare anthropometric parameters in healthy untrained individuals, to measure dynamic balance indicators with YBT-LQ, to measure and calculate as a percentage of absolute error describing the accuracy of the perception of the quadriceps femoris force sense, to find any correlations between the two measurements and to compare the results between the sexes.

Materials & methods

The study was conducted at the University Center for Functional Research in Sports and Kinesitherapy at South-West University "Neofit Rilski"-Blagoevgrad. The testing procedures were approved by the University Ethics Committee. Participants were excluded if they had any injuries to their lower-extremity or spinal dysfunction, had undergone any surgery, had a history of dizziness or falls, showed any visual or inner ear problems, showed any neurological dysfunctions, or showed altered foot sensation. For the purpose of the study, they were informed verbally of the procedures and protocols to be implemented. All participants signed a written informed consent.

Participants

In total, 30 healthy untrained subjects were divided into two groups: men (n = 15) and women (n = 15) aged between 30 and 50 years old. Each of the subjects had to visit the laboratory between 8 and 10 o'clock in the morning on an empty stomach, wearing shorts and a T-shirt. The study was conducted barefoot, except for the torque test. All participants warmed up their lower limbs on a bicycle ergometer before starting the measurements.

Procedures, Measurements and Test protocol

The following anthropometric parameters were registered and measured by bioimpedance analyzer (Ioi) : height (cm), body mass (BM, kg), body mass index (BMI, kg/m^2), lean body mass (LBM, kg), and mass of body fat (MBF, kg). Since, the leg dominance effects should be considered when assessing lower limb dynamic balance neuromuscular performance (Promsri et al., 2020), we divided the legs into dominant and non-dominant, although it was recently found that limb dominance does not affect YBT-LQ performance in non-athlete adolescents (Stoddard et al., 2022). The dominant lower limb was determined based on the participants' answers to the question "Which foot do you use to kick a ball?".

The isometric testing for determination of the individual, maximal isometric torque in Nm, force target and FS protocol, were performed with isokinetic dynamometer system (Biodex 4 Pro). The participants were required to reproduce 50% of the peak isometric torque of m. quadriceps femoris during the FS measurement in both lower limbs. The assessment of FS was based on the criteria for accuracy, as an absolute deviation from the target force, via absolute error (AE) in in percentages (Tsvetkova-Gaberska, Pencheva, 2019). The FS of every leg was measured without visual or verbal feedback.

In order to calculate the composite score (CS), as an integral score from YBT-LQ, each participant's leg length was measured bilaterally in a supine position, as follows: from the spina iliaca anterior superior to the most distal part of the malleolus medialis tibiae (to the nearest half centimeter) (Plisky, 2009).

YBT-LQ requires one leg to balance on a platform, the so-called stance leg, while the contralateral leg, called reaching leg, pushes a board in the anterior (ANT), posteromedial (PM), and posterolateral (PL) directions (Fig. 1). The device has 3 moving boards and one central platform, on which the tested limb as stance leg, steps. There are three pipes in centimeters, which determine the distance in the three directions.

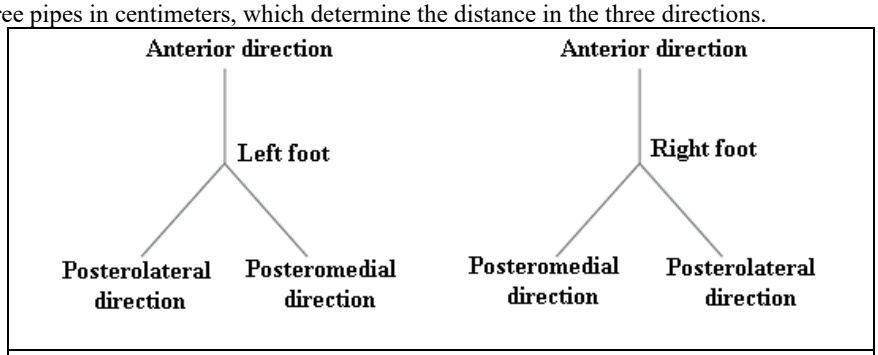

Figure 1. Scheme of the Y balance test for the left and right leg.

YBT-LQ was performed according to the protocol of Plisky et al. (2009). The subjects, barefoot and had their arms at their waists, started YBT with 6 training trials in each direction before the actual testing. The actual measurement was performed in the same order and sequence, with 3 trials, and the highest value was taken. Each participant had to push the boards as far as possible in all three directions, trying not to kick the board, not to step, and return the legs back to the starting position while maintaining the balance of the stance leg. The maximum reached distance was recorded to the nearest 0.5 cm in each direction. The composite score of the three directions in cm, divided by three times the length of the lower limb and multiplied by 100, forms the CS, which is a coefficient for dynamic balance.

Statistical analysis

GraphPad Prism (Version 3.2) was used to analyze the data. All anthropometric parameters and the values of AE, are presented as means with standard deviations (SD), obtained by descriptive statistics. The FS was presented as AE, which is a measure for accuracy, during reproducing of the target isometric force. To assess the statistical significance of the differences between mean values, the nonparametric test of Mann-Whitney, the Kruskal-Wallis ANOVA test, and Dunn's post hoc test, were applied. The Pearson coefficient was used to calculate correlations. A p-value less than 0.05 was used for assessment of statistically significant differences between means and of linear correlations.

Results

The participants in the study were divided into two groups: men - mean age 42.1±8.0 years, and women - mean age 43.3 ± 7.4. The anthropometric characteristics (mean ± SD) of men and women are as follows: height - 173 ± 5 cm and 166.2 ± 4.8 cm, body mass - 84.6 ± 12.2 kg and 64.3 ± 10.2kg, BMI - 26.2 ± 3.3 kg/m^2 and 23.3 ± 3.6 kg/m^2, LBM - 59.4 ± 6.0 kg and 46.5 ± 3.8 kg., MBF - 20.2 ± 6.5 kg and 17.8 ± 7.4 kg respectively. The mean values of leg length in the two studied groups are as follows: 94.2 ± 4.2 cm for men and 88.6 ± 5.4 cm for women. The data show that the participants from the both groups were in the same age range but had distinct sex differences. For example the men are heavier, taller, and have higher BMI, LBM, and MBF values than women. All obtained anthropometric characteristics were normal, which shows that there was no overweight persons, abnormal BMI, LBM, and MBF in either group, and the results are reliable and correspond to the values for healthy people and to the age of the subjects.

The YBT-LQ values for both women and men are shown and summarize the mean ± SD in centimeters (Table 1) for the different directions, and the CS in percent. The distribution of the legs into dominant and non-dominant helped us to analyze the results, when everyone of them is considered to be a stance leg or a reaching leg (instead of left and right).

Table 1. Y-balance test results in anterior-, posteromedial- and posterolateral direction and composite score for non-dominant and dominant leg in healthy subjects (males and females).

Direction	**Participants**		
	Males (n=15)	**Females (n=15)**	**Difference Males / Females**
Anterior direction (cm)			
Non-dominant	**67.2 ± 5.8**	**66.9 ± 5.9**	**NS**
Dominant	**66.9 ± 7.4**	**66.8 ± 6.9**	**NS**
Difference between limbs	**NS**	**NS**	
Posteromedial direction (cm)			

Non-dominant	**104.4 ± 13.3**	**95.2 ± 9.1***	**9.2 ± 4.2**
Dominant	**105.7 ± 13.4**	**93.4 ± 8.9***	**12.3 ± 4.5**
Difference between limbs	**NS**	**NS**	
Posterolateral direction (cm)			
Non-dominant	**106.4 ± 10.0**	**97.8 ± 6.3***	**8.6 ± 3.7**
Dominant	**108.3 ±10.7**	**99.7 ± 5.7***	**8.6 ± 5.0**
Difference between limbs	**NS**	**NS**	
Composite Score (%)			
Non-dominant	**102.1 ±11.8**	**95.3 ± 6.8**	**NS**
Dominant	**103.1 ± 11.9**	**95.4 ± 7.8**	**NS**
Difference between limbs	**NS**	**NS**	

Designations: *Statistically significant difference, as compared with males ($p < 0.05$; Mann Whitney test);

There was no significant difference between the dominant and non-dominant legs, which shows good bilateral symmetry in both sexes in all directions and CS as well. This was a prerequisite for the absence of intra-articular injuries and bilateral muscle weakness and is a sign of the good balance and gait characteristic of healthy people. This was confirmed by the results obtained in the processing of values of AE in percents of the FS (Fig. 2), as for men the values for the dominant limb were: AE= 8.9±4.1% and for the non-dominant: AE= 8.1±3.1% and there was no statistically significant difference between the legs. In women, the FS values were: AE= 10.8±2.7% and AE= 8.7±3.3% dominant and non-dominant, respectively. The higher error values of AE were observed in women, especially in the dominant leg stance.

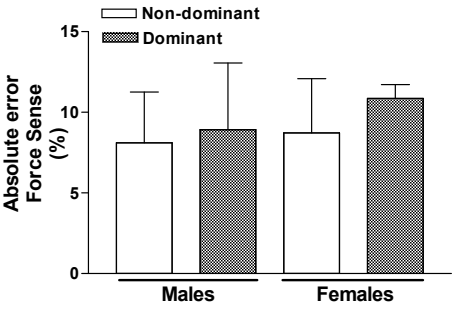

Figure 2. Force sense presented as an absolute error (%) for dominat and non-dominant legs in males and females

There were a significant differences for the values of YBT-LQ between male and female, in the PM and PL directions only, for both dominant and non-dominant leg. For men, the values are statistically significantly ($p<0.05$) higher than for women. The difference between males and females for dominant and non-dominant in the PM and PL directions was as follows: 12.3 ± 4.5 cm and 9.2 ± 4.2 cm; 8.6±5.0cm and 8.6±3.7cm, respectively (Table 1). In these two directions of YBT, the males showed better performance than the females did, when the values of the dominant, and non-dominant legs and the average performance of both legs were compared ($p<0.05$). The CS also showed better performance as compared to the females in both legs, although not statistically significant. The CS values are relevant of those in healthy people, in both studied groups (CS ≥95%).

The moderate negative correlations (r=- 0.68; p=0.005) between AE and the anterior direction of the dominant and non-dominant leg were obtained only in females (Fig 3). In all cases, the value of the FS error decreased as the distance in centimeters in the anterior direction increased. In the case of the dominant supporting leg, it was greater.

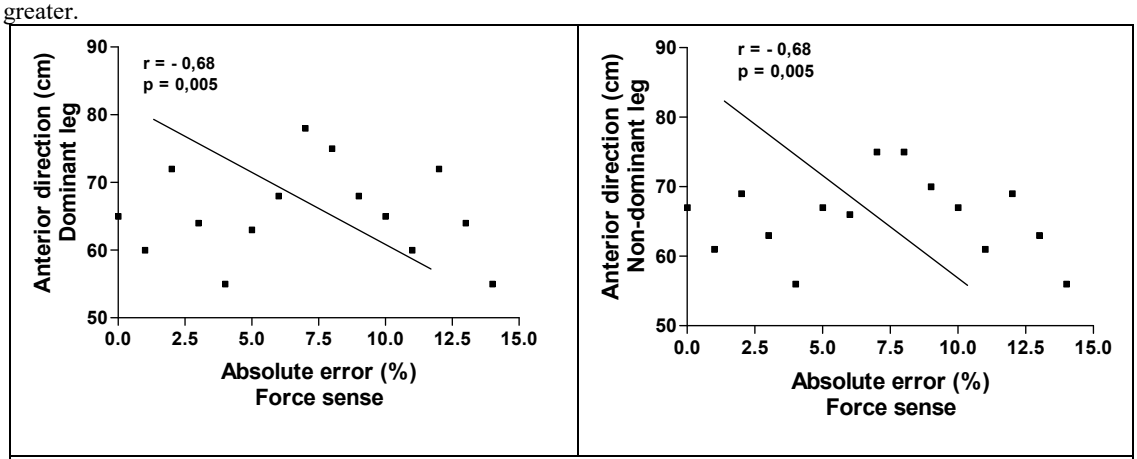

Figure 3. Pearson correlation relationships between anterior direction (cm) of Y-Balance Test Lower Quarter and Force sense (%) calculated as Absolute error (%) in females group

Discussion

In the present pilot study, the dynamic balance was examined with the YBT-LQ test and sex-specific values were obtained for healthy untrained men and women. The range of these values in both sexes can help the interpretation of data from YBT-LQ measurements in everyday clinical and sports practice and the evaluation of the effectiveness of different therapies in patients. Moreover, they could be used as targets during the course of rehabilitation of patients of both sexes.

No statistically significant difference was found in the three measured directions, between dominant and non-dominant leg in both sexes, which prove that the establishing bilateral symmetry, should be considered as important attribute in assessing dynamic balance in healthy, untrained people. The values of the so-called composite score - CS, are also criterion for the bilateral symmetry. The differences between both legs equal to or greater than 4 cm, or values of the CS below 94% are associated with neuromotor deficit, suggesting a higher probability of lower limb injuries (Chimera et al., 2015). The values of CS, obtained in this study are over 95%, which shows that both groups do not have prerequisites for intra-articular injuries of the lower extremities. This allows us to use the data as a reference in future studies on patients and athletes in the same age range.

It is well known that many sports are characterized with asymmetric force models of loading. High quality evidence, demonstrating the relationship between the type and size of asymmetry in various sport discipline and risk factors for injury, are presented in the pertinent literature (Plisky et al., 2021; Neji et al., 2020). Age-related changes in strength can also generate asymmetry and imbalance in the lower extremities, which generate gait disoreders in elderly (Lee et al., 2015).

Some authors reported varying values for asymmetry in reach directions or limb differences, though no relationships to future injury risk were noted (Chimera et al., 2015; Plisky et al., 2009). Few studies have been conducted on the risk of lower limb injuries with YBT-LQ, while most studies on the risk of injury are performed with the Star Excursion Balance Test, due to its great similarity to YBT-LQ and opportunities for more testing directions (Grueva-Pancheva, 2021). For example, asymmetry in the ANT direction greater than 4 cm during Star Excursion Balance Test, indicates which individuals are at risk of injury and intra-articular problems in the lower extremities (Plisky et al., 2009). According to Alnahdi et al., (2015) in study with healthy, untrained, 20-years old male and female, differences between the right and left leg greater than 3.0 cm in men and 1.2 cm in women are outside the normal differences in the ANT direction. They also find a difference between men and women in all directions of measurement by introducing norms for young, healthy persons and reported for the ANT direction 2.8 cm for the dominant and 3.3 cm for the non-dominant leg. According to the results obtained in the present study for ANT direction, the gender difference for dominant and for non-dominant leg are less than 0.3 cm. Probably, the age differences between 20 and 30-50 years in the assessment of the parameters of the dynamic balance, change the range of the norms, the gender differences, the differences between the two legs, etc.

In studies with Star Excursion Balance Test was found significant differences between the limbs in the PM direction in healthy individuals, with no differences in the other directions (Bressel et al., 2007; Neji et al., 2020). These results suggest that comparisons between limbs can be helpful and in this case to serve as an rapid screening for lower limb dysfunction. The results of the comparative studies of groups of men and women are similar to those presented as normative values by Alnahdi et al., (2015). On the other hand, Shaffer et al. (2013) emphasized that the YBT-LQ is a functional test that requires physical strength, flexibility, and neuromuscular control, stability, range of motion, balance, and proprioception. These YBT-LQ data showed statistically significant differences between men and women only in the PM and PL directions. Lee et al., (2015) reported that the values for YBT-LQ in these two directions of movement correlate with the range of motion during abduction and extension in the hip joint and the strength of the flexors in the knee joint. In the present study we also, established that the significant gender differences ($p<0.05$) are observed in the PM and PL directions, but concerns the position a stance leg only, both when it is dominant and when it is non-dominant leg. For example men, as compare with women, reach with dominant leg in PM direction a longer distance - 12.3±4.5 cm, while for PL direction - 8.6±5.0 cm; for the non-dominant leg the values were 9.2±4.2 cm and 8.6±3.7 cm, respectively. The higher YBT-LQ values for the dynamic balance in men for the PM and PL directions are in line with data from other investigations, which claim that gender differences are in these directions and have proven the reliability and discriminant validity of the test (Plisky et al., 2021; Schwiertz et al., 2020). Moreover, Plisky et al., (2021) specifically notes that the YBT-LQ could be used as a tool to identify the deficits in dynamic neuromuscular control.

The less pronounced dynamic balance performance in female may be due to greater muscle mass in men, as a general consideration. Assumptions of earlier development of sarcopenia in women are not acceptable, because evidence has recently been presented that males are more likely to be sarcopenic and to have sarcopenic obesity, than females (Du et al., 2019). It is possible that an decreased ability to perform the dynamic balance task in PM and PL directions in female to be related with an ineffective or minor visual orientation for the values during measurements. Mechanisms of the sensorimotor feedback strategies, which ensure visual orientation and require increased attention, may be the basis of these gender differences and the specifics of sensorimotor manipulations that modulate balance control (Riemann, Lephart, 2002; Rasman et al., 2018).

On the other hand, gender differences are related to age-related changes. Nagasawa et al. (2010) suggest that differences between men and women may play a role separate from the balance strategy according to changes in muscle strength with age, most likely due to hormonal differences between the sexes. The authors found gender differences only in individuals over the age of 60, but age differences began in both sexes after the age of 40 (Freund et al., 2018). The current study identifies gender differences when comparing middle-aged men and women, but the range of 30-50 years suggests age-related changes as well.

Although there was strong evidence for differences in strength between males and females, quantitative assessments of proprioceptive perceptions, in particular, the FS and dynamic balance as a norm in healthy people remain an poorly researched topic in sports and clinical investigations (Tsvetkova-Gaberska, Pencheva, 2019). In the present study, data were obtained on the proprioceptive perceptions of the healthy people regarding the modality of FS, which were assessed by the accuracy criterion as AE. The established negative correlation between FC and the results of dynamic balance assessment, measured with YBT-LQ in women, indicate gender differences in the proprioceptive sense of strength of the knee extensors, which are observed only in the ANT direction. The decrease in FS in women with increasing length of movement in the ANT direction, proves another peculiar aspect of the modulation of the indicators of dynamic balance by the proprioceptive perception. Because the knee plays an important role in maintaining postural and dynamic balance, which is modulated by proprioceptive feedback, the data suggest a greater vulnerability of dynamic balance in women from the level of proprioceptive exercise.

The YTB-LQ has been shown to have a strong relationship with the strength of the knee flexors (Lee et al., 2015). To perform YBT-LQ, subjects bend their torso back and forth to maintain balance, with the upper body creating an isometric peak torque on the knee of the stance leg, because the combinations of lever systems on the back and lower limbs, allow it. According to Zlatkov & Zlatkova (2021), there was a high frequency and prevalence of unspecific low back pain in men and women around the middle age (45.50±9.85 years), which significantly impairs their functionality and performance, especially in the lower quarter. In addition, they reported a high intensity of pain, limiting movement and daily activities, but did not indicate which groups were more likely to suffer from this problem—men or women. Therefore, knee flexors can affect a greater YBT-LQ distance when body tilt changes from forward tilt to backward tilt.

The YBT-LQ allows to quarter the body and look at how the core and each extremity function under the load of body mass. It is a dynamic test in a closed change position, performed in a single-leg stance that requires adequate strength, flexibility, core control, and proprioception, at the limit of the subject's stability. This test requires activity of all of the components of motor control—the lateral and the medial motor system with their efferent pathways and is a tool for assessing the state and disorders of neuromuscular control (Cook et al. 2015; Plisky et al., 2021). Tracking the correlations between proprioceptive perceptions and YBT-LQ results, expands the possibilities for studying the relationships between dynamic balance parameters and proprioceptive feedback.

Conclusions:

A study of the dynamic balance of dominant and non-dominant legs was conducted with YTB-LQ in three directions - ANT, PM, PL, and proprioceptive testing for assessment of FS modality as AE in percentages in healthy males and females with normal anthropometric data, ages 30-50 years. The obtained results from YTB-LQ show no differences in the three directions when comparing dominant and non-dominant legs in both sexes. Establishing bilateral symmetry should be concidered as important attribute in assessing dynamic balance in healthy untrained individuals. The statistically significant differences ($p<0.05$) between the sexes in YTB-LQ in the PM and PL directions were found, which show better levels of dynamic balance in men. In accordance with these findings are the established moderate negative correlations ($p<0.05$) in famales between the values of YTB-LQ in ANT direction and percentages of AE as a criterion of FS accuracy, which suggests that the proprioceptive sense of the quadriceps muscle force of the stance leg is reduced earlier in women, while in men it persists. These results allow to use the range of values for dynamic balance with the YTB-LQ for sports and clinical investigations. On the other hand the evidences for the reduced proprioceptive FS in women only, could be the subject of further research and development of rehabilitation programs to improve dynamic balance and proprioceptive perception of the lower quarter.

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Conflicts of interest - There have been no conflict of interest situations in the course of the research and the publication of the manuscript. The experimental work meets the ethical requirements concerning research and involving the participation of people asset for the Helsinki Declaration.

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