Acute Effects of Gravitational Stretching in the Position of Modified Thomas Test on Changes in Range of Motion in Hip and Knee Joints

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Abstract: Optimal range of motion (ROM) in a joint can improve sports performance and decrease possibility of injury. In kinesiological practice, consisting of physical conditioning and kinesitherapy, ROM is most often achieved by stretching exercise. Modified Thomas Test (MTT) has not yet been used as an intervention for stretching to increase ROM, but only as a test for evaluation of ROM in hip&knee joints. The goal was to determine acute effects of intervention of gravitational stretching of two-joint and one-joint flexors of hip&knee on changes in ROM in the MTT position, by an objective measurement instrument, on young, physically active persons (n=54). Subjects were held in MTT position, and sole force leading to movement of hip&knee joints was a weight of tested extremity. Final results after the intervention were recorded. Identical procedure was repeated for the other extremity. Main results show that 120 seconds of gravitational stretching acutely increases ROM in the hip joint for 4.9° on average, while ROM in knee has decreased for 2.1° on average, and both results have shown statistical significance. MTT, as an intervention for stretching of one-joint hip flexors, is recomended, but not for two-joint flexors, which need another exercise to yield positive effects.

1 INTRODUCTION

Achieving an optimal range of motion (ROM) in the hip and knee may increase physical ability as well as reduce the risk of injury (Lobel et al., 2016). Optimal ROM can be achieved in a variety of ways, and in kinesiological practice - composed of conditioning preparation and kinesitherapy - is most often achieved by increasing flexibility through stretching exercises. During stretching it is important to ensure that the tension occurs in the musculoskeletal unit rather than in the ligaments that maintain joint stability (Knudson, 1998). Flexibility as a component of performance and health fitness can be defined by intrinsic property of the soft tissues (muscles, ligaments, fascia etc.), which all determines the ROM in one or more joints, without injury or tissue damage (Holt et al., 1996). Flexibility is not but one factor that may affect the ROM, and we can measure it through static and dynamic diagnostic tests. The assessment of static flexibility refers to the usual linear and angular measurements of actual constraints in the joint or the joint complex, having the elements of subjectivity due to variations in the raters experience and the respondent's tolerance to muscle stretching. Dynamic flexibility is an increase in activity of muscle groups to resist stretching (stiffness) during movement and is a less subjective measure of flexibility (Knudson et al., 2000). Inactivity and immobilization lead to a decrease in static (passive) ROM and an increase in the stiffness of the muscle group (Knudson, 2007; Akeson et al., 1987; Heerkens et al., 1986). Long-term stretching programs are most likely to increase the static ROM by stimulating the formation of new sarcomers in muscle fibers (De Deyne, 2001) and changes in neuro-muscular factors (Guissard and Duchateau, 2006). Also, the mechanism of progress of the subjects in passive stretching is the result of autogenous inhibition and muscular tension (Knudson, 2007). Some studies suggest that muscle relaxation is primarily the result of tension-induced stresses that are responsible for an increase of ROM during passive stretching (Tanigawa, 1972; Taylor, 1990; Medieros, 1977), while other explain the effects of long-term intensive stretching through reduced muscular viscosity and hysteresis, without changing tendon stiffness (Kubo et al., 2001, 2002). In addition, ROM in a joint is strongly associated with the position of the body segments due to passive tension that is being

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increased in each musculo-tendon unit, especially in multi-joint musculo-tendon units - passive insufficiency (Knudson, 2007). Limited hip extension ROM is probably a result of disturbance in the rigidity of the hip flexor muscles, as evidenced in subjects with lower limb pain symptoms and functional constraints in the hip and knee (Winters et al., 2004). Kendall et al. (2005) defined the rigidity of hip flexor muscles as an inability to achieve a complete hip extension in the position of the Modified Thomas test (MTT), although there were no evidence that the ROM deficiency is the result of a lack of muscle extensibility. Studies considering measurement of ROM in the hip usually examine the effects of stretching on 1) pain in the lumbar back (Kuukkanen and Malkia, 2000), 2) sports training (Van Mechelen et al., 1992; Magnusson, 1998; Witvrouw et al., 2003), 3) the walking function (Christiansen, 2008; Godges et al., 1989) and 4) the evaluation of the results of the hip surgery (Shields et al., 1995; McGrory, 1996). The ROM in the hip is also used as a diagnostic test for lumbar pain, through the test of lifting the leg and help in the diagnosis of osteoarthritis (Rebain et al., 2002; Pua et al., 2008; Theiler et al., 1996; Arokoski et al., 2004; Aalto et al., 2005). The goal of rehabilitation protocols used in the treatment of the most common musculo-skeletal injuries of the lower extremities such as, for example, patelofemoral syndrome is an increase of the existing insufficient muscle flexibility of the *rectus femoris* muscle (Peeler and Leiter, 2013; Beckman et al., 1989; McConnell, 2002; Shelton, 1992). MTT is a standardized observational clinical test of posture, postural adaptation, and lower extremity kinematics. It also provides information on the flexibility of hip and knee muscles, most notably *m. iliopsoas, m. rectus femoris, m. tensor fasciae latae, m. sartorius*. In clinical practice, MTT is often used to assess the passive ROM while extending the hip and flexing the knee. The test is in practice most often of a subjective character, since it is assessed on the basis of observation as positive or negative in relation to established norms (Kendall et al., 2005; Magee, 2006; Cheatham and Kolber, 2016). The estimation of the length of the muscles of the lower extremities is carried out indirectly - by measuring the ROM of the hip and knee and by comparing the results bilaterally and in relation to the normative values. The normative values of the length of the muscles of the lower extremities, i.e. the hip and knee ROM, are important for the prevention of injuries through the detection of reduced flexibility (Corkery et al., 2007). The stated subjectivity of MTT makes it hard to use within the evidence-based paradigm of medicine. As a rule, in clinical conditions it is not enough to make such a dichotomous assessment, but the ROM should be quantified for the purpose of an objective evaluation of the condition of the respondents, the presence of dysfunction or injury, and the progress through rehabilitation. The objectification of the test most often includes goniometric (Corkery et al., 2007; Ferber et al., 2010; Harvey, 1998; Clapis et al., 2008; Wang et al., 1993), and trigonometric (Wakefield et al., 2015; Peeler and Anderson, 2007) methods as well as the method of digital photography (Peeler and Leiter, 2013; Vigotsky et al., 2015). 2D goniometry is considered a gold standard and is carried out using a goniometer or inclinometer device. The test is considered positive if the leg being tested does not reach the neutral horizontal position or inferior (Kendall et al., 2005; Magee, 2006; Corkery et al., 2007; Clapis et al., 2008). According to Kendall et al. (2005) the inability of the passive extension of the hip to the neutral position indicates the tension of the one-joint hip flexors (*m. iliopsoas*), while the inability of the knees to passively flex over 80° leads to the shortening of the two-joint hip flexors (*m. rectus femoris, m. tensor fasciae latae, m. sartorius*). An additional presence of abduction and internal rotation of the hip indicates a shortening of *m. tensor fasciae latae*, and the external rotation of *the hip* on a shortening m. sartorius. The MTT assessment in clinical practice encompasses the ROM observation analysis in all three planes of movement, and is described in the literature accordingly (Kendall et al., 2005; Cheatham and Kolber, 2016), however in published research (Corkery et al. 2007; Ferber et al., 2010; Harvey, 1998; Wakefield et al., 2015; Clapis et al., 2008; Wang et al., 1993; Peeler and Anderson, 2007; Peeler and Leiter, 2013; Kim and Ha, 2015; Vigotsky et al., 2015; Peeler and Anderson, 2008), the authors were focused exclusively on measuring the movement in the sagittal plane.

According to the available literature, only one published paper was found showing the 3D kinematic analysis of the MTT performed by the optoelectronic system (Moreside and McGill, 2011), while the acute effects of the gravitational stretching of monoarticular and biarticular hip and knee flexors in the MTT position have not yet been investigated. The authors of this paper participated in the publication of a study on the reliability of the optoelectronic system in relation to the goniometer as a gold standard in practice, with the Spearman coefficient of correlation of 0.91 (Kiseljak et al., 2017).

Table 1: Results of the study of stretching effects on the hip and knee ROM with the tests used, the intervention on individual muscles and the performance protocol. (Legend: ASLR – active straight leg raise test).

AUTHORS	SAMPLE	TEST FOR ASSESSMENT	MUSCLES	PROTOCOL	RESULTS
Young et al. 2004	Young athletes n=16	MTT	m. iliopsoas; m. qudricepsfemoris	3 static stretching exercises with 30-second position retention, 3 repetitions	Hip ROM: +1.4^0; Knee ROM: -0.7^0 No significance
Yildirim et al. 2016	Students n=26	ASLR	m. hamstrings	3 times a week, 10 repetitions of static stretching exercises, 30 seconds of position retention	Hip ROM: +4.7^0 Statistically significant
Czaprowski et al. 2013	Children n=94	MTT	m. iliopsoas	6 weeks once per week static exercise sessions; 4x30 seconds with 30 seconds pause	Hip ROM: + 6.4^0 Knee ROM: +2.8^0 Statistically significant
Curry et al. 2009	Young girls n=24	MTT	m. iliopsoas m. gluteus m. qudriceps femoris m. hamstrings m. soleus m. gastrocnemius	10 minutes of static stretching; 3x12 seconds with 12 seconds rest	Hip ROM: +6.5^0 Statistically significant
Vigotsky et al. 2015	Young people of both genders n=23	MTT	m. tensor fasciae latae m. quadriceps femoris	Myofascial relaxation with roller; 2x 60 seconds of rolling	Hip ROM: +1.39^0 No significance
Lobel et al. 2016	Young moderately active women n=18	MTT ; upright hip flexion and extension	m. iliopsoas	Static stretching; 4x 60 seconds only for the right leg	Hip ROM: +8.1^0 Statistically significant
Bandy et al. 1997	People with a limited movement of the hip; both genders n=93	ASLR	m. hamstrings	Static stretching; 6 weeks, 5x a week; Group 1: 3x 1minute; Group 2: 3x 30 seconds; Group 3: 3x 1 minute; Group 4: 1x 30 seconds	Hip ROM s most effective when stretching for 30 seconds; the other groups were not statistically significant from the group that had 30 seconds stretching
Halbertsma et al. 1996	Students with limited general movement in the hip n=14	ASLR	m. hamstrings	One-time 10-minute stretching; 30 seconds of passive stretching - 30 seconds rest	Hip ROM: +8.9^0 Statistically significant
Winters et al. 2004	Young people with limited movement in the hip n=33	MTT	m. iliopsoas	Static stretching for 6 weeks; 2 exercises, 10x 30 holding positions with 8 seconds rest	Hip ROM: +13^0 Statistically significant

The aim of this paper is to determine the acute effects of the intervention of the gravitational stretching of the two-joint and one-joint hip flexors on the ROM changes in the MTT position among younger, physically active individuals by using the objective measuring instrument. Knowing the effect of gravitational stretching on changes in ROM of hip and knee could contribute to the prevention and rehabilitation of hip joint injuries and in the prevalence of the most commonly injured joint of the knee, as well as the optimization and maximization of the training process used for the improvement of fitness abilities.

2 METHODS

2.1 Participants

The research was conducted in the Biomechanics Laboratory, a part of the Institute of Kinesiology at the Faculty of Kinesiology, University of Zagreb, in May 2016. The randomized subject sample was composed of 54 male participants (n = 108 lower extremities) of 21.89 ± 1.41 years of age, body height 181.58 ± 5.23 centimeters and body mass 81.71 ± 9.42 kilograms. As previous studies found that stretching effects were dependent on the time spent in the stretching position, a control group that did not perform stretching exercises was not required for this study (Bandy et al., 1997; Halbertsma et al., 1996). Participants were recruited from the student population of various faculties. A high level of physical activity of the sample was found by the Croatian version of the International Physical Activity Questionnaire (IPAQ) questionnaire (Pedišić et al., 2011). No respondent for two years had any injuries or surgery as documented by a specially constructed anamnestic questionnaire. The respondents were required to be completely rested for measurement, which included at least 12 hours without any physical activity. The pre-test warming-up protocol was not performed in order to try to achieve real sports and clinical conditions (Cejudo et al., 2015; Aalto et al., 2005). All measurements were carried out at approximately the same time of day, in the afternoon. Prior to the experiment, the participants were familiarized with the measurement protocol, the potential contribution of the research and possible discomfort during the implementation of the latter, and signed the informed consent for the voluntary participation in the research. The Ethical Commitee of the Faculty of Kinesiology approved the implementation of the research and all ethical principles were respected.

2.2 Procedure

For the research purposes, a special MTT clinical test was used. The kinematic features of the MTT were evaluated using the objective 3D method of the automated optoelectronic kinematic measurement system ELITE 2002 BTS (Elaboratore di Immagini Television 2002 Bioengineering and Technology Systems, Milano) containing 8 cameras, sampling frequencies of 100 Hz with 9 passive markers (Medved and Kasović, 2007; Chiari et al., 2005; Moreside and McGill, 2011). The measurement was performed bilaterally, initially immediately after the MTT and finally after 120 seconds in the relaxed MTT position, or after the gravitational stretching intervention for each lower limb. The duration of optimal stretching was selected according to the American College of Sports Medicine (ACSM) guidelines (Taylor et al., 1990; Lobel, 2016). The dependent variables studied were changes in the hip and knee joint angles. After completing the anamnestic, IPAQ and participation questionnaires, anthropometric measurements and the setting of passive markers on the body were applied. The extremity to be measured first was randomized.

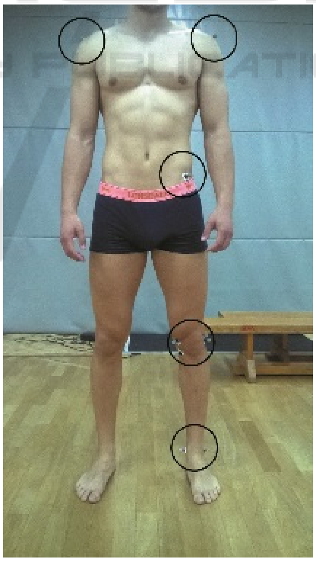

Figure 1: Respondent with placed markers on the body prominences: 1 - acromion Right (R), 2 – acromion Left (L), 3 - anterior superior iliac spine (ASIS) L, 4 - medial femoral epicondyle L, 5 – medial tibial epicondyle L, 6 - lateral femoral epicondyle L, 7 – fibular head L, 8 - medial malleolus L and 9 - lateral malleolus L.

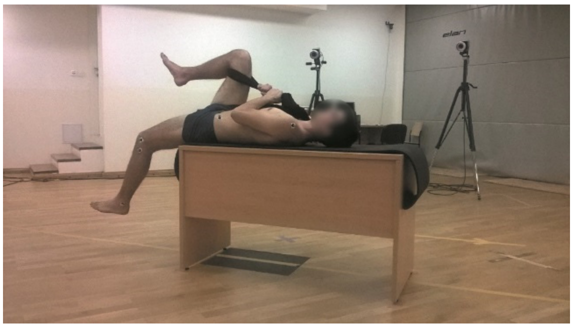

Figure 2: Respondent in the MTT position.

The passive markers were set by palpation to exactly defined anatomic points: acromion L + R: set on both sides, anterior superior iliac spine (ASIS) L / R: positioned on only one side, medial femoral epicondyle L / R, lateral femoral epicondyle L / R, fibular head L / R, medial tibial epicondyle L / R, medial malleolus L / R, and lateral malleolus L / R. After marker placement, respondents were positioned for MTT and all the instructions for performing a test were given according to a protocol based on information from relevant literature (Kendall et al., 2005; Magee, 2006; Cheatham and Kolber, 2016; Harvey, 1998): the subject laid in supine position on the table, with a pelvis at the bottom of the table and holding both knees by chest. This ensures that the lumbar spine is in a neutral position tied to the surface. The lumbo-pelvic region and the thigh of the nontested leg are stabilized passively by an immobilization strap at an angle of 120°. The greater or lesser hip flexion angle leads to the loss of the position of the neutral spine. Following is a standardized instruction for the subject to take a deep breath and, with exhaling, to allow the gravity to guide the gradual movement of the extension of the hip with flexion of the knee of the examined extremity. The only force that leads to these movements is the weight of the tested limb. After performing the MTT, the examiner provides acquisition of kinematic signals (joint angles) for the initial measurement. Furthermore, each subject lies 120 seconds completely relaxed at the MTT position and allows the gravity to act to stretch the active limb, and after finishing the intervention, the final position have been recorded. The same procedure was repeated for the second limb.

2.3 Signal Acquisition and Processing

Acquisition and processing of kinematic signals was carried out via specially designed GaitEliClinic and SmartAnalyzer software from BTS. The feature of the BTS ELITE system is to enable the measurement of high spatial (millimeter order) and time resolution as well as automatic detection and acquisition of coordinates of particular markers. The system is based on the automatic detection of the coordinates of the retroreflective markers by the cross-correlation method, and by using the close-range photogrammetry algorithms for calculation of marker coordinates. When the marker path is known, it is possible to calculate certain kinematic parameters of the recorded motion (Medved, 2001; Medved, 2014). From the aforementioned program, angles in the hip and knee joint were acquired. A total of 432 angles were evaluated, out of which 22 had disappeared from the experiment due to subjects' skin sweating and loss of signal, artefact of soft tissue and passive system (Leardini et al., 2005) and a lumbar spine movement (neutral position loss), so in total 410 angles were finally processed.

2.4 Statistical Analysis

The obtained measurement results were processed in the program package Statistica for Windows 12.0 (Statsoft, Tulsa, USA). Descriptive parameters were calculated (mean, standard deviation, minimum and maximum value, skewness and kurtosis). The normality of distribution of variables was examined using the Kolomogorov-Smirnov test. Differences between initial and final measurements were evaluated using the t-test for large dependent samples and the Wilcoxon pair test. The level of statistical significance was set at the $p \leq 0.05$.

3 RESULTS

Descriptive parameters are shown in Table 2. Hip-related data is normally distributed while knee-related data are not. Therefore, the t-test for large dependent samples was used to evaluate the significance of the difference between the initial and final measurement of the hip ROM, and between the initial and final knee ROM measurements the Wilcoxon pair test was used. The main results of this study are shown in Table 3 and 4 and show that there is a statistically significant difference between the initial and final measurements in the hip and knee joint.

Table 2: Descriptive knee and hip stretching parameters, initial (I) and final (F) measurements.

Variable	N	mean (μ)	minimum	maximum	standard deviation (σ)	skewness	kurtosis
I knee	103	53.91	26.88	98.79	12.36	0.92	1.60
F knee	103	51.80	28.98	92.30	10.33	1.20	2.60
I hip	102	-21.89	-48.80	-0.25	8.34	0.04	0.69
F hip	102	-26.71	-53.68	-9.51	8.08	-0.30	0.49

Table 3: T-test for large dependent samples of variables of the initial (I) and final (F) measurements of the hip (significant differences at $p < 0.05$).

pair of variables	N	T	df	P
I hip and F hip	102	10.96	101	0.000000

Table 4: Wilcoxon test for a pair of dependent variables of initial (I) and final (F) knee measurements (significance at $p < 0.05$).

pair of variables	N	T	Z	P
I knee and F knee	103	1574.00	3.63	0.000281

4 DISCUSSION

Based on searched and available literature, we found no study that used MTT as an intervention. Otherwise, it was used only as a test for estimating the one-joint and two-joint hip flexors ROM. Contrary to the Thomas test (TT) performed in a fully supine position at the testing table (Magee, 2006; Cheatham and Kolber, 2016; Peeler and Anderson, 2007), the MTT is carried out in a supine position on the table, with a pelvis and a hips at the edge of the table, which allows the movement of the tested thigh below the horizontal line as well. For this reason, MTT provides the ability to evaluate not only monoarticular, but also biarticular hip flexors. Today, in research and clinical practice, MTT is more common than TT. The inability of the thigh of the tested limb to reach the neutral position or fall below the horizontal is considered a positive MTT (Kendall et al., 2005; Magee, 2006; Corkery et al., 2007; Clapis et al., 2008). However, for clinical practice, and especially for research purposes, such dichotomous assessment of the test is insufficient. Many special clinical tests lack quantitative dimension, which makes them difficult to apply for scientific purposes and they remain only a tool of everyday practice. Orthopedic thus special clinical tests can help to determine if a particular type of dysfunction or injury is present or potential (Magee, 2006). Corkery et al. (2007) state that the lack of flexibility in *m. rectus femoris*, measured by MTT could be identified as a predictor for hamstrings injury in amateur athletes. Individuals with ≤51° flexion of the knee were identified with more prone to hamstrings injury. Aforementioned authors consider the estimation of *m. rectus femoris* length as an important part of the evaluation of the athletes' condition and prevention of injuries due to its biarticular functions. The imbalance between the right and left hip extension movement at the level of the posture, function, and muscle structure are associated with a predisposition for lower limb injury. Wang et al. (1993) used MTT to estimate the length of *m. iliopsoas* and found no significant differences between athletes and non-athletes. The authors argue that the reason for this is the result of the fact that respondents from both groups spend a lot of time sitting, which brings this muscle to a shortened position.

Corkery et al. (2007) positioned the examinees (n = 72) in the full supine position on the table (TT) for the evaluation of the hip ROM, with an average angle of extension -2.3° ± 1.9° (flexed position 2.3° above the horizontal). The study included initial warming-up on the stationary bicycle with a predetermined intensity throughout the 3 minutes in order to standardize the level of physical activity before measurement. A similar approach to the research with the warm-up protocol had Wang et al. (1993), Young et al. (2004), Curry et al. (2009), Vigotsky et al. (2015), and thus prepared the respondents prior to the application of the stretching and testing protocol. In this study, the respondents did not carry out any warm-up, as in studies of Lobel et al. (2016) and Bandy et al. (1997), so as not to affect the results. Furthermore, 12 hours prior to the measurement, physical activity was banned in order to achieve the real clinical conditions. In the literature, only Peeler and Leiter (2007; 2008) included such an elimination criterion (they set the limit 4 hours prior to testing) but did not perform warm-up before the measurement. Disadvantage of the research made by Wakefield et al. (2015) is testing only the right lower limb on a small sample (n = 22), and at Corkery et al. (2007) did not randomize extremity testing, thus the right leg was always tested before the left, which could have an impact on the results.

Young et al. (2004) presented the results similar to ours with an increase in ROM in the hip by an average of 1.4° and a decrease in the knee by 0.7°, but the results are not statistically significant. Czaprowski et al. (2013) studied the influence of static stretching in children combined with active stabilization exercises that proved to be effective in increasing ROM. Changes in the ROM were statistically significant, and the increase was 6.4° for the hip and 2.8° for the knee. The authors believed that the muscles were not actually shortened, but according to the assumptions of Sahrmann (2002), Mottram and Comerford (2006), the muscles replaced the stabilization function and the muscles are more likely to be weaker than shortened. According to the same authors, two-joint hip flexors that can also affect the knee joint are more often shortened and may be responsible for a limited hip ROM. Stretching duration or stretching program portion is one of the most important factors contributing to the increase in ROM in the hip, and Aalto et al. (2005) according to previous research (Roberts and Wilson, 1999; Borms et al., 1987; Bandy et al., 1997) advise that 30 seconds is sufficient time to retain stretching of the hamstrings muscles to increase ROM. Magnusson (1998) has proven that one static stretch results in a 30% greater relaxation of viscous-elastic muscle strain. The results of this study show that 120 seconds of gravitational stretching in the MTT position is statistically significant in increasing the hip ROM along with a decrease in knee ROM which is in agreement with previous studies. Based on these findings, in the training practice, it could be recommended to use this intervention for stretching the one-joint hip flexors, but for stretching the two-joint hip flexors, another exercise should be used to achieve the results in increasing the ROM. In this paper as well as in the previous work of the same group of authors (Kiseljak et al., 2017), the normative values for the young active population of hip and knee ROM were measured by the automatized optoelectronic system and as such independent of the examiner as in the case of using a goniometer. The aggravating factors in measuring with the goniometer showed the impossibility of precisely positioning the fixed and movable arms toward prominent anatomical points, and the difficulty in placing the center of the instrument in the projection of the point of rotation axis in the joint. The disadvantages of this study and the application of such a system in practice were the cost of having laboratories and instrumentation, as well as additional time spent in relation to the standard 2D goniometry for the preparation of the system and the passive markers. Standardization of the procedure can accelerate the speed and precision of 3D extension, abduction and rotation ROM measurement in the hip with the isolation of human error or fatigue. In future studies it is necessary to investigate the acute effects of stretching in the MTT position in the female population, older and less physically active individuals, as well as individuals with different pathologies of the lower limbs and ROM restrictions in hips and knees. It is necessary to determine whether 30 or 60 seconds is sufficient for achieving stretching effects, or part of the time spent in performing stretching exercises should be used for other kinesitherapeutic and conditioning tasks. In addition, optoelectronic kinematic assessment for objectivization among other standard observational clinical tests is prospective, with the objective to establish normative values and forming a reliable evaluation method.

5 CONCLUSION

The study shows that 120 seconds of gravitational stretching in the MTT position is sufficient time to achieve acute effects on the increase in ROM in the hip, but the same is not presented for ROM in the knee. The main results show that 120 seconds of static stretching acutely increase the hip ROM by an average of 4.9°, while the knee ROM decreased by an average of 2.1°, and both results are statistically significant. On the basis of the abovementioned results in training practice it is proposed to use MTT for stretching of the one-joint hip flexors, and for the elongation of the two-joint hip flexors, it is necessary to select and use another intervention or exercise that will achieve results in increasing the ROM. In addition, it is also reasonable to use an automatized optoelectronic kinematic assessment system not only for research purposes, but for the application in clinical practice. Future research should deepen knowledge about the acute effects of stretching in the MTT position on the female population and in less physically active people as well as persons with restrictions in hip and knee ROM. The results of such prospective studies could provide a significant contribution in the prevention and rehabilitation of injuries as well as improvements in motor abilities.

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