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Step down tests are the tasks that most differentiate the kinematics of women with patellofemoral pain compared to asymptomatic controls.

Lateral step down is the task that most differentiates women with patellofemoral pain compared to asymptomatic controls

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ABSTRACT

Background

Studies evaluating kinematics lead to different conclusions, not all changes appear in all assessed tasks and in all subgroups of patients with patellofemoral pain (PFP). The inconsistencies between studies could be reduced if we knew which task separates patients best from healthy controls.

Research Question

Identify which functional task, between gait, forward step down (FSD), lateral step down (LSD), stair ascent and descent and propulsion and landing phase of the single leg hop test (SLHT), differentiates the three-dimensional kinematics of women with patellofemoral pain from asymptomatic women.

Methods

This cross-sectional study evaluated thirty-five PFP and thirty-five asymptomatic women during the execution of the following tasks: gait, FSD, LSD, stair ascent and descent and the propulsion and landing phase of single leg hop test. Frontal, sagittal and transverse plane angles of the trunk, pelvis and hip, frontal and sagittal plane angles of the knee, ankle dorsiflexion, foot progression angle and hindfoot eversion were analyzed through the Movement Deviation Profile (MDP). To compare the groups, the multivariate analysis with Bonferroni post hoc test were used, with a significance level of $p<0.01$. To identify which task presented the most difference between the groups, the Z-score of the mean MDP was calculated.

Results

For all tasks, the groups presented significant differences. According to the Z-score, the groups got farther apart considering the MDP for each task in the following order: LSD (7.97), FSD (7.62), landing phase of SLHT (3.43), gait (2.85), propulsion phase of SLHT (1.64), descending stairs (1.63) and ascending stairs (1.00).

Significance

We suggest that step down tests should be included in the assessment of PFP patients, since these tests most differentiate the kinematics of women with and without PFP. Identifying the tasks with the highest sensitivity to detect the kinematic differences is expected to improve clinical decision-making.

Keywords: Kinematics, Lateral step down, Step down tests, Patellofemoral pain, Movement Deviation Profile

HIGHLIGHTS

All analyzed tasks differentiate the kinematics between PFP and asymptomatic women.

MDP can be used to differentiate the kinematics of PFP from asymptomatic women.

Step down tests are the tasks that most differentiate the kinematics of PFP women.

The LSD has the highest sensitivity to detect the kinematic differences.

PFP kinematic differences are less evident in stair ascent and descent.

INTRODUCTION

Patellofemoral pain (PFP) is a multifactorial clinical condition characterized by retro- and/or peripatellar pain with an annual prevalence of approximately 23% in the general population and a point prevalence of 12-13% in 18-35 year old females [1–4]. Kinematic changes such as greater trunk inclination, pelvic drop, adduction and internal rotation of the hip, poor alignment and/or maltracking of the patella, internal rotation of the tibia and excessive pronation of the subtalar joint are associated with patients with PFP [5–8]. However, kinematic changes are not always observed in all groups of patients with PFP and in all analyzed tasks [9].

The lack of standardization of the functional tasks used to assess patients with PFP makes it difficult to compare studies and interpretation of results for clinical practice [10]. It is not known if the kinematic changes found can be considered tasks-dependent, if the treatment should be directed to the task to be assessed and if there is a task that most differentiates the individual with PFP from the healthy individual [10,11].

The Movement Deviation Profile (MDP) is an artificial neural network based method that calculates the deviation of a patient's movement from normality [12,13]. The MDP unifies and simplifies the understanding of kinematic data, since the analysis of several angle curves in three anatomical planes describing the movement of several joints poses a difficult challenge [12].The MDP has never been explored with PFP patients. This analysis can help to differentiate a set of kinematic variables between groups of individuals considering the temporal waveforms of several variables in a given cycle of movement, as opposed to comparing discrete variables like peak values of joint movements and their timing. Providing a simplified summary measure of multivariate temporal data is an attempt to help clinicians to interpret the results of a kinematic analysis more easily and to guide their decision making towards functional tasks which show more kinematic changes in women with PFP.

The identification of a task that makes the biomechanical changes of the patient with PFP more evident could help researchers and clinicians to make a decision regarding the assessment, treatment evolution and improving movement control of these patients, by making the interpretation of the results and the comparison between the studies easier. Therefore, the objective of this study was to identify which functional task, between gait, forward step down (FSD), lateral step down (LSD), stair ascent and descent and propulsion and landing phase of the single leg hop test (SLHT), differentiates the three-dimensional kinematics of women with patellofemoral pain from asymptomatic women. Gait and stairs represent daily tasks and the tests are usually used in clinical trials to quantify the improvement in the function of the patient with PFP after treatment and assess lower limbs abilities as functional muscle strength, power and neuromuscular control.

METHODS

Study Design

This is a cross-sectional study carried out at a Laboratory of Analysis of the Human Movement of the Nove de Julho University between 2013 and 2016.

Subjects

Invited by means of oral invitation, 35 women with patellofemoral pain and 35 asymptomatic women aged between 18 and 35 took part in the study. In the group of women with patellofemoral pain those who were included showed anterior knee pain for at least three months during performance of at least two of the following tasks: ascending and descending stairs, squatting, running, jumping or remaining seated for a long time, besides showing a minimal score of 3 points in the Numerical Pain Rating Scale (NPRS) [14]. The NPRS consists of a scale from 0 to 10 points, where higher scores characterize higher intensity of pain [14]. The first clinical examination of the volunteers was conducted by two experienced physiotherapists to verify the eligibility criteria [15].

The symptomatic or more symptomatic limb of the PFP group was assessed and the side of the control group was matched to the painful side of the patients. The demographic data of each group are shown in Table 1.

Table 1. Demographic data of the control group and the PFP group.

	Control Group Mean (SD)	**PFP Group Mean (SD)**
N	35 (22R/13L)	35 (22R/13L)
Age (years)	24.68 (3.53)	25.60 (6.74)
Body mass (kg)	57.77 (9.20)	57.31 (7.32)
Height (m)	1.63 (0.06)	1.60 (0.06)
BMI (kg/m²)	21.45 (2.28)	22.29 (2.44)
NPRS (0-10)	0	6.42 (1.33)

N: number of volunteers assessed; R: right lower limb assessed; L: left lower limb assessed; BMI: Body mass index; NPRS: Numerical Pain Rating Scale; SD: Standard Deviation

The exclusion criteria for both groups were: history of surgical procedures of the lower limbs, recurrent patellar instability, associated ligament and/or meniscal injuries, cardiac or locomotion disorders that could interfere with the assessment, as well as leg length difference higher than 1 cm. In the control group of asymptomatic women, the volunteers did not report any musculoskeletal pain in the lower limbs.

Procedures and Instruments

All assessments were carried out in a single day. The volunteers eligible for the study were informed about the details of the study and those who agreed to participate signed the informed consent form. The institutional ethics committee approved the study (protocol number 124.075).

The kinematic analysis of the following functional tasks was performed: gait, forward step down, lateral step down, stair ascent and descent and the propulsion and landing phase of the single leg hop test. For the group of women with patellofemoral pain the intensity of the pain was assessed using the NPRS [14].

The anthropometric data of each subject required for the reconstruction of the biomechanical model including mass, height, length of lower limbs, distance between the anterior superior iliac spines and the diameter of the knees and ankles were measured before the placement of the kinematic markers. A total of 43 retro reflective markers were fixed to the skin at specific anatomical locations of the lower limbs and trunk of each volunteer included in the study, using hypoallergenic double-sided tape, according to the Plug-in Gait and Oxford Foot Model [16,17]. The Vicon system consisting of eight infrared cameras operating at a frequency of 120 Hz was used to acquire kinematic data. The Vicon Nexus software (version 1.8.5) was used for data acquisition and processing.

After the placement of the markers, the participants received verbal explanation, followed by a demonstration of how to perform each task. The kinematic data were only collected after the volunteers were familiarized with each task.

Functional Tasks

Between all tasks and series of movements that were performed, two minute long breaks were held. All collections and verbal commands were performed by a single physiotherapist. The order for the execution of the tasks was always the same for all volunteers: gait, FSD, LSD, stair ascent, stair descent, SLHT.

Gait

The volunteers were instructed to walk as naturally as possible at self-selected speed on a 6-meter-long by 1-meter wide track.

Forward Step Down and Lateral Step Down

The FSD and LSD tasks consisted of three sets of three consecutive squats standardized at 60° knee flexion [11]. A step measuring 18 cm high, 30 cm wide and 30 cm deep was used to perform both tasks. For the FSD it was requested that the foot of the assessed limb be centrally positioned on the step, near the end of its anterior edge and the contralateral foot was held at the same height in front and in the air. For the LSD the medial border of the foot was be aligned with the lateral edge of the step and the contralateral limb was held in the air immediately to the side. The initial position of the limb tested in both tasks was maximal extension of the knee on the support side, while the contralateral limb had to remain with the knee completely extended and the ankle in maximum dorsiflexion, arms crossed and close to the trunk throughout the execution of the tasks.

The volunteer was asked to perform the squats slowly, over two seconds, and immediately return to the initial position, also over two seconds, in each repetition requested.

Ascending and Descending Stairs

The task of ascending and descending stairs was performed on three steps, 20 cm high and 30 cm deep each without handrails [18]. During ascent the volunteer took two steps before making the initial contact with the first step. For the descent the volunteers were instructed to take at least two steps after the end of the stairs. Both ascent and descent had to be performed with limbs alternating between the steps at a self-selected speed, so for each repetition of the task a cycle of one stair ascending and one stair descending were collected.

Single Leg Hop Test

The test consisted of a single one-legged horizontal jump with the assessed limb in support. The volunteer was asked to keep her arms crossed and close to her trunk and to remain in one-legged support with the knee of the assessed limb in extension. Under the evaluator’s command the volunteer should jump horizontally as far as she could without putting the contralateral limb on the ground at the time of landing. The test was divided into two phases: the propulsion phase and the landing phase.

Data Processing

After the reconstruction of the markers, the movement cycle for each task was identified as described above. For gait, ascent and descent of stairs, kinematic variables of the support and swing phases of the cycle were analyzed; for the FSD, LSD, propulsion and landing the eccentric (squatting) phase and the concentric phase were analysed. The descriptions of each task cycle and the number of cycles considered for analysis are in the Supplementary Data.

The kinematic data were filtered using the Woltring filter applied with 2 mean squared errors (2MSE) to the marker trajectories to reduce noise due to soft tissue artefacts causing marker movement during the movement cycle.

For all tasks, the following kinematic variables were considered: the frontal, sagittal and transverse planes of the trunk and pelvis segments in relation to the laboratory, hip in relation to the pelvis, frontal and sagittal planes of the knee in relation to the thigh, sagittal plane from the foot in relation to the shank, the transverse plane of the foot in relation to the laboratory, and the frontal plane movement of the hindfoot in relation to the tibia.

Movement Deviation Profile (MDP)

The MDP uses a self-organizing map (SOM), a type of artificial neural network which employs unsupervised learning. The neural network was first trained with control data, and the data from each healthy subject and patient were presented to the trained SOM which compared their movement data to the learned distribution of normality. The SOM calculates the multidimensional Euclidean distance between each patient and normality, providing a single curve for each patient which reflect the distance from normality during the whole duration of the movement [12].

For each patient and each task, an MDP curve was calculated in relation to the control group consisting of a series of 51 data points of 14 kinematics curves in 9 trials. The mean of the 51 points of the MDP curves (MDP_{mean}) of each group was considered for the statistical analysis.

Statistical Analysis

The z-score was calculated by subtracting the average MDP_{mean} of the control group from the average MDP_{mean} of the PFP group divided by the standard deviation of the control group's MDP_{mean} in each task to compare the standardized results between the groups. Multivariate analysis to verify the interaction between groups with Bonferroni *post hoc* test was used, considering a $p<0.01$.

RESULTS

The multivariate analysis showed interaction between groups ($F=358.11$, $p<0.0001$). The MDP curves representing each task compared between groups are shown in Figure 1. The means and confidence intervals (95%) of the MDP are available on supplementary data. All tasks presented significant differences between groups with $p<0.01$ (Bonferroni *post hoc* test). According to the z-score of the mean MDP, the groups got farther apart for each task in the following order: LSD (7.97), FSD (7.62), landing phase of SLHT (3.43), gait (2.85), propulsion phase of SLHT (1.64), descending stairs (1.63) and ascending stairs (1.00) (Figure 2).

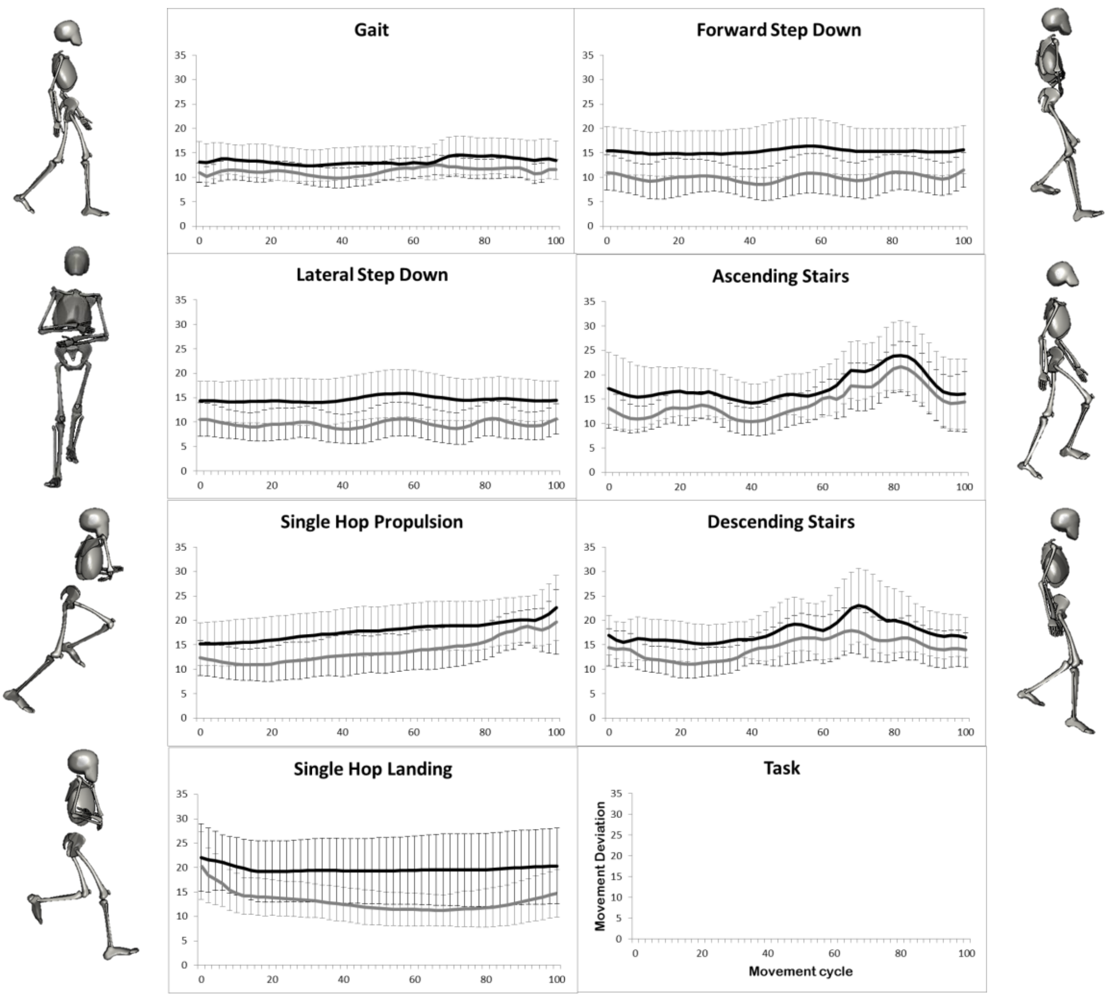

Figure 1. The Movement Deviation Profile chart (mean and standard deviation bands) summarizes the 14 angle curves of each task for participants with patellofemoral pain (black) and the control group (grey) during the movement cycle.

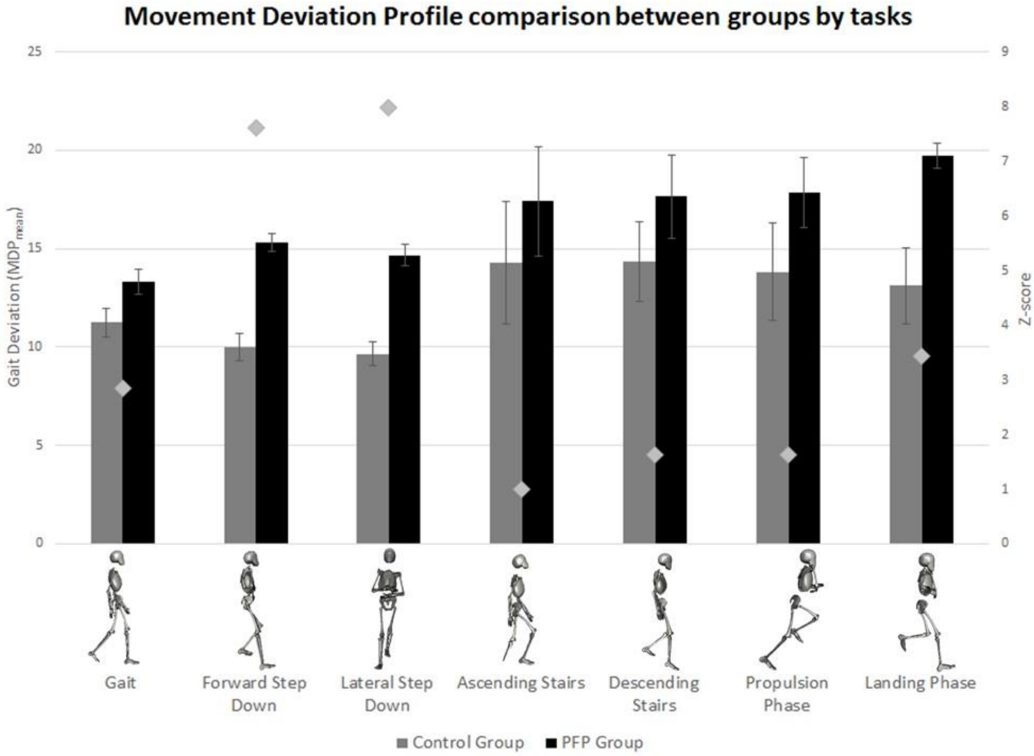

Figure 2. Means and standard deviations of MDP graphics and Z-score (diamonds) of task deviations between the PFP group and controls for each task.

DISCUSSION

LSD and FSD are clinical tests that assess the quality of movement based on the observation of the trunk, pelvis and lower limb alignment [19–22]. During LSD, patients with PFP present greater adduction and internal rotation of the hip [23], movements that can expose the patellofemoral joint to excessive loads and increased stress causing pain symptoms [1,10,23–25]. In addition to the hip, changes such as poor movement quality and increase of the movement of the ankle-foot complex and hindfoot eversion are also found in patients with PFP and may contribute to increased differences in kinematics when compared to asymptomatic individuals during LSD [21,23,26].

Although both tests are a one-legged squat, where one of the lower limbs is fixed on a step, the positioning of the contralateral limb makes the biomechanics of the tests different. During the FSD the contralateral lower limb is positioned forward maintaining the pelvis in anterior/ external rotation, the hip flexed, the knee extended and the ankle dorsiflexed. The assessed lower limb (support side) performs the task by initiating movement from the external rotation of the pelvis, internal rotation and extension of the hip, extension of the knee and neutral position of the ankle. From the initial positioning, squats occur predominantly with movements of flexion and extension of the hip and knee and dorsiflexion of the ankle. Supposedly, LSD demands more of the action of the muscles that control the movements in the frontal plane of the pelvis and hip than the FSD, since the position of the contralateral limb is parallel to the assessed limb, and this way may have contributed to the LSD differentiated women with and without PFP a little more than FSD.

Despite the fact women with PFP show kinematic changes in the trunk, pelvis, hip and ankle during the propulsion phase of the one-legged jump [7], these changes were not enough to differentiate the groups as well as with LSD, FSD, landing and gait. Women with PFP who were assessed may have adopted other motor strategies to perform propulsion satisfactorily, avoiding movements that could cause pain, since kinetic and electromyographic changes are also observed in the hip and knee in this group of patients [7].

During the one-legged landing, the kinematic changes found between women with and without PFP occur at different time in the task cycle [8]. It is known that moments before the landing of a one-legged jump and in its eccentric phase, women with PFP present an increase in the electromyographic activity of muscles that involve the knee joint, and this a possible mechanism of joint protection and stabilization to avoid the pain that the impact of the task can cause in the patellofemoral joint [27,28]. It is worth noting that kinematic changes do not seem to be influenced by the impact and demand of the task on people with PFP [29].

In spite of the lower reaction force and mechanical challenges to the joint at the patellofemoral joint during gait compared to stair ascent and descent [30], gait was able to better differentiate the kinematics of women with PFP than stair ascent and descent or the propulsion phase of the jump. The peak and the time of hindfoot eversion, internal rotation and adduction of the hip are the main differences between individuals with and without PFP during gait [31,32]. Besides, the trunk segment and the swing phase offers scarcely explored variables during the gait analysis of patients with PFP but these were included in our study and may have contributed to increase the differences between the groups.

The findings in the literature regarding the kinematic alterations of patients with PFP during ascending and descending stairs are inconsistent [33,34]. Novello et al. [18] pointed out that stairs, more specifically the descent, may not be the best task to highlight the kinematic differences that women with PFP possibly present and should be used with caution in the assessment and clinical decision making for the treatment of patients with PFP .

This study presents some limitations in that pain during the execution of the tasks was not assessed. Besides, it is a study carried out only with women, and by being aware of the differences between the genders, it is suggested that future studies should assess men with PFP to identify the task that best distinguishes them from asymptomatic men. Another limitation is that we did not randomize the order of tasks, but the kinematic differences between individuals with and without PFP appear to be uninfluenced even after an effort protocol [29].

Identifying the tasks that maximize the kinematic differences between women with and without PFP can help clinicians in the decision making about which tasks to assess, compare and track improvements during treatment of these patients. The tasks that show the kinematic changes of PFP patients best probably require better motor and neuromuscular control and can be used to draw the most detailed profile about these patients and develop a treatment plan with a focus on improving these biomechanical factors.

MDP can help to identify at which percentage of the tasks the deviation patient’s movement is more different from normality and assist clinicians in being more directive and assertive in a conventional kinematic analysis that are needed to identify the cause of these differences. Future studies identify the role of each joint and each movement plane in the tasks for differentiation between groups and understand what possible strategies or neuromuscular changes may be behind these differences in the biomechanics of women with and without PFP. As well as consider also the whole cycle of tasks, the swing in the gait and the stairs and the concentric and eccentric phases of the squats and the propulsion and landing of jumps. We believe that important changes can be present in those phases that the literature, to date, has not studied sufficiently.

We conclude that step down tests are the tasks that most differentiate the kinematics of women with and without PFP. We suggest that LSD and FSD be included in the assessment of patients with PFP, but we emphasize that this result does not exclude the option of assessing the other tasks, because all of them showed differences between the groups and also because of being a multifactorial dysfunction. It is important to consider the symptomatology, occupation, physical activity and biopsychosocial factors of each patient assessed at the time of prescribing the treatment and the inclusion of the other tasks in the assessment when clinician deems necessary.

REFERENCES

[1] K.M. Crossley, J.J. Stefanik, J. Selfe, N.J. Collins, I.S. Davis, C.M. Powers, J. McConnell, B. Vicenzino, D.M. Bazett-Jones, J.-F. Esculier, D. Morrissey, M.J. Callaghan, 2016 Patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester. Part 1: Terminology, definitions, clinical examination, natural history, patellofemoral osteoarthritis and patient-reported outcome m, Br J Sport. Med. 50 (2016) 839–843.

[2] B.E. Smith, J. Selfe, D. Thacker, P. Hendrick, M. Bateman, F. Moffatt, M.S. Rathleff, T.O. Smith, P. Logan, Incidence and prevalence of patellofemoral pain: A systematic review and meta-analysis, PLoS One. 13 (2018) e0190892.

[3] J.R. Roush, R. Curtis Bay, Prevalence of anterior knee pain in 18-35 years old female, Int J Sports Phy Ther. 7 (2012) 396-401.

[4] C.M. Powers, L.A. Bolgla, M.J. Callaghan, N. Collins, F.T. Sheehan, Patellofemoral Pain: Proximal, Distal, and Local Factors—2nd International Research Retreat, August 31–September 2, 2011, Ghent, Belgium, J. Orthop. Sport. Phys. Ther. 42 (2012) A1–A54.

[5] C.M. Powers, The Influence of Altered Lower-Extremity Kinematics on Patellofemoral Joint Dysfunction: A Theoretical Perspective, 2003.

[6] G.B. Salsich, W.H. Perman, Tibiofemoral and patellofemoral mechanics are altered at small knee flexion angles in people with patellofemoral pain., J. Sci. Med. Sport. 16 (2013) 13–7.

[7] A.S. Bley, J.C.F. Correa, A.C. Dos Reis, N.D.D.A. Rabelo, P.H. Marchetti, P.R.G. Lucareli, Propulsion Phase of the Single Leg Triple Hop Test in Women with Patellofemoral Pain Syndrome: A Biomechanical Study, PLoS One. 9 (2014) e97606.

[8] A.C. dos Reis, J.C.F. Correa, A.S. Bley, N.D. dos A. Rabelo, T.Y. Fukuda, P.R.G. Lucareli, Kinematic and Kinetic Analysis of the Single-Leg Triple Hop Test in Women With and Without Patellofemoral Pain, J. Orthop. Sport. Phys. Ther. 45 (2015) 799–807.

[9] C.M. Powers, E. Witvrouw, I.S. Davis, K.M. Crossley, Evidence-based framework for a pathomechanical model of patellofemoral pain : 2017 patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat , Manchester , UK : part 3, Br J Sport. Med. (2017) 1–11.

[10] E. Witvrouw, K. Crossley, I. Davis, J. McConnell, C.M. Powers, The 3rd International Patellofemoral Research Retreat: an international expert consensus meeting to improve the scientific understanding and clinical management of patellofemoral pain., Br. J. Sports Med. 48 (2014) 408.

[11] N.D.D.A. Rabelo, P.R.G. Lucareli Do hip muscle weakness and dynamic knee valgus matter for the clinical evaluation and decision-making

process in patients with patellofemoral pain? Braz. J. Phys. Ther., 22 (2018), pp. 105-109

[12] G.J. Barton, M.B. Hawken, M.A. Scott, M.H. Schwartz, Movement Deviation Profile: A measure of distance from normality using a self-organizing neural network, Hum. Mov. Sci. 31 (2012) 284–294.

[13] G.J. Barton, M.B. Hawken, M.A. Scott, M.H. Schwartz, Leaving hip rotation out of a conventional 3D gait model improves discrimination of pathological gait in cerebral palsy: A novel neural network analysis., Gait Posture. 70 (2019) 48–52.

[14] R.A. Da Cunha, L.O.P. Costa, L.C. Hespanhol, R.S. Pires, U.M. Kujala, A.D. Lopes, Translation, Cross-cultural Adaptation, and Clinimetric Testing of Instruments Used to Assess Patients With Patellofemoral Pain Syndrome in the Brazilian Population, J. Orthop. Sport. Phys. Ther. 43 (2013) 332–339.

[15] N.D. dos A. Rabelo, L.O.P. Costa, B.M. de Lima, A.C. dos Reis, A.S. Bley, T.Y. Fukuda, P.R.G. Lucareli, Adding motor control training to muscle strengthening did not substantially improve the effects on clinical or kinematic outcomes in women with patellofemoral pain: A randomised controlled trial, Gait Posture. 58 (2017) 280–286.

[16] M.P. Kadaba, H.K. Ramakrishnan, M.E. Wootten, Measurement of lower extremity kinematics during level walking, J. Orthop. Res. 8 (1990) 383–392.

[17] M.C. Carson, M.E. Harrington, N. Thompson, J.J. O'Connor, T.N. Theologis, Kinematic analysis of a multi-segment foot model for research and clinical applications: a repeatability analysis., J. Biomech. 34 (2001) 1299–307.

[18] A. de A. Novello, S. Garbelotti, N.D. dos A. Rabelo, A.N. Ferraz, A.S. Bley, J.C.F. Correa, F. Politti, P.R.G. Lucareli, Descending stairs: Good or bad task to discriminate women with patellofemoral pain?, Gait Posture. 65 (2018) 26–32.

[19] J.E. Earl, S.K. Monteiro, K.R. Snyder, Differences in Lower Extremity Kinematics Between a Bilateral Drop-Vertical Jump and A Single-Leg Step-down, J. Orthop. Sport. Phys. Ther. 37 (2007) 245–252.

[20] K.-M. Park, H.-S. Cynn, S.-D. Choung, Musculoskeletal Predictors of Movement Quality for the Forward Step-down Test in Asymptomatic Women, J. Orthop. Sport. Phys. Ther. 43 (2013) 504–510.

[21] A. Rabin, Z. Kozol, U. Moran, A. Efergan, Y. Geffen, A.S. Finestone, Factors Associated With Visually Assessed Quality of Movement During a Lateral Step-down Test Among Individuals With Patellofemoral Pain, J. Orthop. Sport. Phys. Ther. 44 (2014) 937–946.

[22] S.R. Piva, K. Fitzgerald, J.J. Irrgang, S. Jones, B.R. Hando, D.A.

Browder, J.D. Childs, Reliability of measures of impairments associated with patellofemoral pain syndrome., BMC Musculoskelet. Disord. 7 (2006) 33.

[23] J.E. Earl, J. Hertel, C.R. Denegar, Patterns of Dynamic Malalignment, Muscle Activation, Joint Motion, and Patellofemoral-Pain Syndrome, J. Sport Rehabil. 14 (2005) 216–233.

[24] A. Silva, F. Politti, A. Novello, C. Ferreira, N. Rabelo, N.E. Akalan, P. Lucareli, P85: Kinematic sensitivity and specificity to detect differences between women with patellofemoral pain and healthy women during the lateral step down test?, Gait Posture. 57 (2017) 323.

[25] T.C. Liao, N. Yang, K.-Y. Ho, S. Farrokhi, C.M. Powers, Femur Rotation Increases Patella Cartilage Stress in Females with Patellofemoral Pain, Med. Sci. Sport. Exerc. 47 (2015) 1775–1780.

[26] dos Reis, Amir Curcio; Garbelotti Junior, Silvio Antonio; Rabelo, Nayra; Lima, Bruna; Contani, Luciane; P.R.G. Lucareli, Kinematic analysis of ankle-foot complex mobility during weight acceptance functional tests in patellofemoral pain women, Gait Posture. 49 (2016) 74–75.

[27] M.M. Kalytczak, P.R.G. Lucareli, A.C. dos Reis, A.S. Bley, D.A. Biasotto-Gonzalez, J.C.F. Correa, F. Politti, Kinematic and electromyographic analysis in patients with patellofemoral pain syndrome during single leg triple hop test, Gait Posture. 49 (2016) 246–251.

[28] M.M. Kalytczak, P.R.G. Lucareli, A.C. dos Reis, A.S. Bley, D.A. Biasotto-Gonzalez, J.C.F. Correa, F. Politti, Female PFP patients present alterations in eccentric muscle activity but not the temporal order of activation of the vastus lateralis muscle during the single leg triple hop test, Gait Posture. 62 (2018) 445–450.

[29] J.D. Willson, S. Binder-Macleod, I.S. Davis, Lower Extremity Jumping Mechanics of Female Athletes with and without Patellofemoral Pain before and after Exertion, Am. J. Sports Med. 36 (2008) 1587–1596.

[30] I.G. Goudakos, C. König, P.B. Schöttle, W.R. Taylor, N.B. Singh, I. Roberts, F. Streitparth, G.N. Duda, M.O. Heller, Stair climbing results in more challenging patellofemoral contact mechanics and kinematics than walking at early knee flexion under physiological-like quadriceps loading, J. Biomech. 42 (2009) 2590–2596.

[31] C.J. Barton, P. Levinger, H.B. Menz, K.E. Webster, Kinematic gait characteristics associated with patellofemoral pain syndrome: A systematic review, Gait Posture. 30 (2009) 405–416.

[32] M. Arazpour, F. Bahramian, A. Abutorabi, S.T. Nourbakhsh, A. Alidousti, H. Aslani, The Effect of Patellofemoral Pain Syndrome on Gait Parameters: A Literature Review., Arch. Bone Jt. Surg. 4 (2016) 298–306.

[33] L.A. Bolgla, T.R. Malone, B.R. Umberger, T.L. Uhl, Hip Strength and Hip and Knee Kinematics During Stair Descent in Females With and Without

Patellofemoral Pain Syndrome, J. Orthop. Sport. Phys. Ther. 38 (2008) 12–18.

[34] K. McKenzie, V. Galea, J. Wessel, M. Pierrynowski, Lower Extremity Kinematics of Females With Patellofemoral Pain Syndrome While Stair Stepping, J. Orthop. Sport. Phys. Ther. 40 (2010) 625–632.