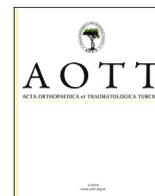




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Alterations in energy consumption and plantar pressure distribution during walking in young adults with patellofemoral pain syndrome

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ABSTRACT

Objective: The aim of this study was to determine the alterations of walking energy expenditure and plantar pressure distribution in young adults with patellofemoral pain syndrome (PFPS).**Methods:** Thirty five individuals (mean age: 21.31 ± 1.76) with PFPS constituted the patient group and forty healthy participants (mean age: 21.40 ± 2.11) the control group. Preferred walking speeds (PWS) were determined on the over ground. Individuals walked on a treadmill for 7 min at their PWS and 30% above PWS and oxygen consumption was recorded via a metabolic analyzer. Net oxygen consumption was calculated for each walking trial. Borg scale was applied to assess perceived exertion during walking trial. Plantar pressure distributions were measured by a pedobarography device. Plantar area was subdivided into six zones to evaluate the dynamic plantar pressure data.**Results:** The mean PWS of PFPS and control groups were 4.69 ± 0.51 and 4.52 ± 0.60 km/h, respectively ($p > .09$). No significant difference was observed in energy expenditure during walking at PWS between 2 groups while oxygen consumption during 30% above PWS was higher in patient group (18.72 ± 3.75 and 16.64 ± 3.27) ($p = .007$). Net oxygen consumption was also found to be higher in PFPS group (15.12 ± 3.62 and 13.04 ± 3.24) ($p = .005$). The mean Borg scores were significantly higher in PFPS group at each walking trials ($p < .001$). No statistically significant difference was found between weight distribution (%) of symptomatic and nonsymptomatic extremity ($50.45 \pm 3.92\%$ and $49.56 \pm 3.93\%$, respectively) ($p = .509$). Dynamic pedobarography parameters were not different between 2 groups, and also between symptomatic and nonsymptomatic extremities ($p > .05$).**Conclusion:** Although, rate of perceived exertion and energy expenditure during walking at 30% above PWS are affected negatively in young adults with PFPS, we may speculate that energy consumption and plantar pressure distribution can be compensated by a physiologic adaptation mechanism during walking at PWS.**Level of evidence:** Level III, Therapeutic Study.© 2018 Turkish Association of Orthopaedics and Traumatology. Publishing services by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Introduction

Patellofemoral pain syndrome (PFPS) is a pathology commonly seen in athletes and physically active young adults that causes

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physical and functional insufficiency in turn affect daily life activities negatively.¹ Despite its high incidence, there is no consensus about etiology of PFPS. Various factors like overuse, quadriceps weakness, and lower extremity dynamic malalignments can be responsible for this syndrome.^{2–4}

The major complaint of patient with PFPS is usually retropatellar pain that is activated during prolonged sitting and walking, squatting, ascending and descending stairs. The aggravation in pain with these activities is related with the increased patellofemoral joint

reaction forces.⁵ Patients with PFPS develop compensatory strategies like avoiding knee flexion during stance phase of gait to reduce the patellofemoral joint reaction forces and also the pain.^{6,7} The other mechanism that may affect gait biomechanics in PFPS patients is the imbalance theory of primary dynamic patellar stabilizers.⁸

It has been accepted that patellofemoral joint is affected by alignment of the lower extremity. Dynamic malalignments of lower extremity kinematics such as excessive hip adduction, internal rotation, and excessive and/or prolonged foot pronation during walking are usually indicated as potential risk factors for PFPS.^{9–11} One of the indirect ways of investigating dynamic malalignment during locomotion is to evaluate plantar pressure distribution during walking.¹¹ A prospective research has indicated that the higher pressure at medial colon of the plantar area was correlated with higher foot pronation.¹² Another prospective study has stated a relationship between PFPS and the lateralized support of plantar surface.¹⁰

We hypothesized that these biomechanical changes may also alter energy consumption of physical activities. It is well accepted that energy consumption of walking is affected by pathological or compensatory changes in gait.¹³

The purpose of present study was to investigate the energy consumption of walking, to determine the plantar pressure distribution in young adults with and without PFPS and to compare symptomatic and nonsymptomatic foot during stance phase of walking.

Patients and methods

Subjects

The study consisted of 2 groups, PFPS and control group. The sample size determination was based on a two sided type I error rate 0.05, the power of 0.80 according to the reference study.¹⁴ We calculated 35 patients per group. All of the PFPS and control group were physically active young adults. Participants of the study were students at School of Physical Education and Sports Teaching. Age, height and body mass index (BMI) matched young adults participated in our study. The control group consisted of 40 young adults (21.40 ± 2.11 years). The inclusion criteria's for the control group were, no history of any knee pathology or trauma and no limitation that would interfere with normal gait.

The PFPS group was included 35 young adults (21.31 ± 1.76 years) who had a characteristic history and symptoms of unilateral patellofemoral pain syndrome for at least six months. All subjects were examined by the same orthopedic surgeon. They were excluded if they had any previous knee surgery, any other knee pathology or any other back, lower extremity problems that may impair walking ability (such as pes planus, pes cavus, equinovarus, excessive pronation, supination, genu varum and valgum etc.) and also a history of patellar dislocation and had received any treatment for PFPS that would influence gait biomechanics. Meniscal and anterior cruciate ligament (ACL) pathologies were also excluded by magnetic resonance imaging.

Physical activity levels of participants during last 7 days were identified by using the long version of the self-administered International Physical Activity Questionnaire.¹⁵ Patellofemoral pain at different positions was scored using a visual analog scale (VAS).¹⁶ All subjects gave their written informed consent, which was approved by the local ethical committee before test procedures.

Anthropometric assessment

A universal goniometry was used to measure active hip, knee and ankle range of motion.¹⁷ Active range of motion (ROM)

measurements were performed by the same investigator. The average of 2 measurements was taken.

Oxygen consumption

The determination of PWS, energy expenditure measurements and data analysis methods were explained in detail in one of our previous study.¹⁸ For the energy expenditure measurements of walking, subjects were asked to walk at PWS and 30% above PWS on the a motor-driven treadmill at 0% grade for 7 min. Previous studies in our laboratory have shown that the speed 30% above PWS was not forced the subject to run, but it was more intense walking than PWS.¹⁸

Net O₂ consumption was determined for each walking trial using the following formula: Net O₂ consumption = "Total O₂ consumption – resting O₂ consumption" and the other method of the calculation the net O₂ consumption = "Total O₂ consumption – standing O₂ consumption". The respiratory quotient (RQ) values of walking trials were also recorded to evaluate the intensity of the walking trials. Borg scale was applied to assess perceived exertion.¹⁹

Plantar pressure assessment

Plantar pressure data were collected at a sampling frequency of 300 Hz by using a pressure plate (Footscan® RScan International, Olen, Belgium). Subjects were asked to stand on the pressure plate with facing straight ahead and arms at sides to determine load distribution as percentage on symptomatic and nonsystematic extremities at static condition. For the dynamic plantar pressure measurements, all subjects were asked to walk at their PWS over the pressure plate for 10 times. Average value of 3 valid trials was recorded from both foot and analyzed to ensure reliability of pressure data.¹² Same extremities was used to make plantar pressure measurement comparison between PFPS and control group. Plantar area was subdivided into six zones to evaluate the dynamic plantar pressure data^{20,21} (Fig. 1). Contact area (%), peak pressure (N/cm²), and impulses (Ns/cm²) beneath these areas were also calculated.

Statistics

Shapiro–Wilk test was used to test the normal distribution of continuous variables. Parametric methods were used if it was necessary. The mean comparisons of 2 independent groups were done via Student t test. Paired sample t-test was used for 2 dependent groups' comparisons. The relationship between categorical variables was evaluated by Chi square test. Descriptive statistics of continuous variables were given as means and standard deviations, and categorical variables were expressed as frequencies and percentages. Statistical analysis was performed using by SPSS 11.5 (SPSS, Inc., Chicago, IL). $p < 0.05$ was considered as statistically significant.

Results

There was no statistically significant difference between 2 groups in terms of the distribution of subjects in groups according to gender ($p = .126$). The mean symptom duration was 18.34 ± 15.96 months (range 6–53). The mean \pm SD of demographic and anthropometric data of the subjects in each group were presented in Table 1.

The major complaints of patients with PFPS were; recurrent swelling in 6 (17.14%), locking in 7 (20%), crepitus in 24 (68.57%), giving away in 17 (48.57%), and decreased activity levels in 35 (100%) patients.

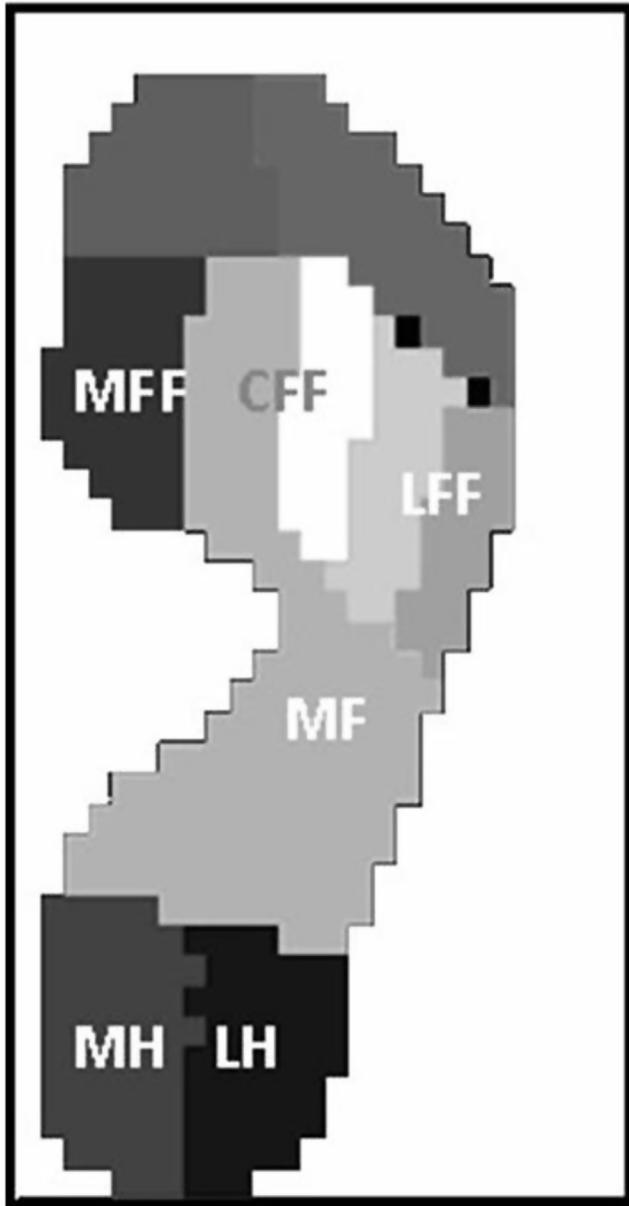


Fig. 1. The location of six anatomical sub-areas on footprint. (Footscan software 7, Footscan® RScan International, Olen, Belgium).

The result of IPAQ indicated that physical activity level of control group was significantly higher than PFPS group (8952.52 ± 7427.94 and 7612.88 ± 5231.40 MET min/week, respectively ($p = 0.007$)). The pain severities of different positions of patients were shown in Fig. 2.

Lower extremities' ROM results of PFPS and control groups, and also the symptomatic and nonsymptomatic legs in PFPS group were

Table 1 Demographic and anthropometric characteristics of patients and control subjects.

	PFPS Mean (SD) (N = 35)	Control Mean (SD) (N = 40)	p
Age (years)	21.31 ± 1.76	21.40 ± 2.11	0.991
Height (cm)	167.82 ± 7.18	170.82 ± 8.66	0.112
Body weight (kg)	60.14 ± 8.63	63.47 ± 9.43	0.129
BMI (kg/m ²)	21.26 ± 1.82	21.66 ± 2.15	0.389
Body fat (%)	15.86 ± 4.78	14.27 ± 5.89	0.087

BMI: Body mass index.

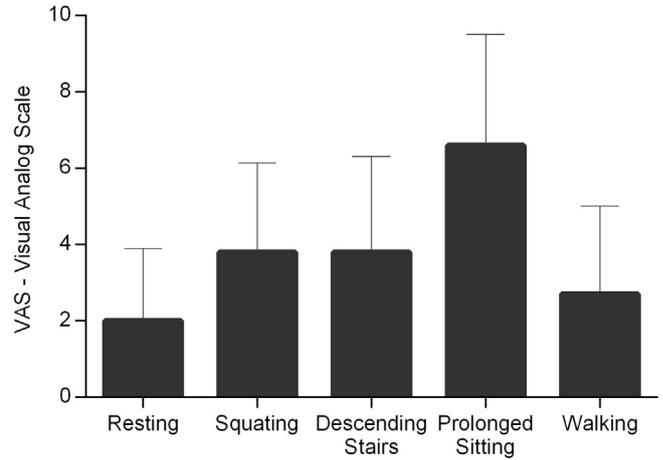


Fig. 2. The pain severities in different positions of the patients.

summarized in Table 2. Knee hyperextension, ankle dorsiflexion, ankle inversion and ankle eversion were significantly reduced in PFPS group than control group ($p < .05$). In addition, knee flexion and hyperextension angle were found to be significantly different against to the symptomatic extremity ($p < .05$) (Table 2).

The mean PWS of PFPS and control groups were 4.69 ± 0.51 and 4.52 ± 0.60 km/h, respectively ($p > .05$). Oxygen consumption parameters of PFPS and control groups were presented in Table 3. There was no significant difference between 2 groups in term of oxygen consumption during walking at PWS ($p > .05$). Oxygen consumption during walking at %30 above PWS was found to be higher in PFPS group ($p < .05$). There was no statistically difference between groups with regard to RQ values during resting and standing conditions ($p > .05$) (Table 3). The mean Borg scores were significantly higher in PFPS group at 2nd, 4th and 7th min. of each walking trials ($p < .001$) (Table 4).

No statistically significant difference was found between weight distribution (%) of symptomatic and nonsymptomatic extremity according to the static pedobarographic measurements ($50.45 \pm 3.92\%$ and $49.56 \pm 3.93\%$, respectively) ($p > .05$). The results of dynamic plantar pressure analyses taken of different regions of 2 groups and symptomatic and nonsymptomatic extremities were summarized in Table 5.

Discussion

The present study has revealed that oxygen consumption during walking at PWS was not different between groups. However, it was found to be higher among the subjects with PFPS during walking at %30 above PWS compared to the healthy counterparts.

The adaptation to the negative impacts of PFPS can be maintained by the selection of the walking speed by the central nervous system that the main determinant of walking energy consumption is the PWS.^{22,23} The PWS's of PFPS group of the current study contradict the result reported by Powers and colleagues who found significant decreases in PWS in patients with PFPS. They suggested that slower walking speed in patient PFPS group might be an attempt by these patients to minimize the patellofemoral joint forces.²⁴ Finding of no difference in PWSs among the groups might be the result of patients were young and physically active in our study.

The alterations in walking speed may lead changes in the gait parameters.^{25,26} We may consider that during walking at PWS there were no extreme differences in lower extremity kinematics and balance mechanisms, so the subjects could maintain the energy

Table 2

Active range of motions of lower extremities in PFPS and control groups and symptomatic and nonsymptomatic legs in PFPS group.

ROM (°)	PFPS Mean (SD) (N = 35)	Control Mean (SD) (N = 40)	p	Symptomatic Leg Mean (SD) (N = 35)	Nonsymptomatic Leg Mean (SD) (N = 35)	p
Hip internal rotation	49.34 ± 8.36	46.55 ± 7.65	0.136	49.34 ± 8.36	48.97 ± 8.31	1.000
Hip external rotation	37.25 ± 6.44	39.90 ± 5.73	0.037*	37.25 ± 6.44	48.97 ± 8.31	0.493
Knee flexion	133.48 ± 6.82	135.82 ± 5.08	0.187	133.48 ± 6.82	135.31 ± 5.35	0.004*
Knee hyperextension	9.03 ± 1.99	11.10 ± 1.74	0.001*	9.03 ± 1.99	9.97 ± 1.76	0.003*
Ankle plantar flexion	53.20 ± 6.84	56.15 ± 8.40	0.070	53.20 ± 6.84	53.54 ± 7.48	0.737
Ankle dorsi flexion	22.20 ± 4.41	24.62 ± 3.49	0.017*	22.20 ± 4.41	22.74 ± 6.13	0.675
Ankle inversion	30.91 ± 8.02	36.72 ± 6.13	0.001*	30.91 ± 8.02	30.94 ± 8.97	0.821
Ankle eversion	24.80 ± 7.55	28.02 ± 6.22	0.018*	24.80 ± 7.55	24.94 ± 7.46	0.811

*Statistically significant differences ($p < 0.05$) in the goniometric measurements.**Table 3**

Oxygen consumption result of PFPS and control groups.

	PFPS Mean (SD)	Control Mean (SD)	p
Resting VO ₂ ml/kg/min	3.60 ± 0.46	3.60 ± 0.41	0.911
S – VO ₂ ml/kg/min	4.30 ± 0.54	4.31 ± 0.53	0.939
W – VO ₂ ml/kg/min	13.47 ± 2.06	12.63 ± 1.86	0.068
W – RQ	0.79 ± 0.04	0.77 ± 0.05	0.006*
W30 – VO ₂ ml/kg/min	18.72 ± 3.75	16.64 ± 3.27	0.007*
W30 – RQ	0.83 ± 0.50	0.78 ± 0.04	0.001*
Net oxygen consumption1 (W- Resting) ml/kg/min	9.86 ± 1.93	9.02 ± 1.75	0.053
Net oxygen consumption2 (W30- Resting) ml/kg/min	15.12 ± 3.62	13.04 ± 3.24	0.005*
Net oxygen consumption3 (W-S) ml/kg/min	9.16 ± 1.91	8.31 ± 1.80	0.052
Net oxygen consumption4 (W30-S) ml/kg/min	14.42 ± 3.65	12.33 ± 3.25	0.006*

*Statistically significant differences ($p < .05$) in the oxygen consumption parameters. S: Standing energy expenditure; W: Walking energy expenditure at self-selected speed; RQ: Respiratory quotient; W30: Walking energy expenditure at 30% more of preferred walking speed.**Table 4**

The mean Borg scores in both walking trail at 2nd, 4th and 7th min in PFPS and control groups.

Borg score	PFPS Mean (SD)	Control Mean (SD)	p
Walking at PWS-2nd min.	7.83 ± 2.41	6.15 ± 0.53	0.001
Walking at PWS-4th min.	8.48 ± 2.34	6.17 ± 0.38	0.001
Walking at PWS-7th min.	9.00 ± 2.63	6.22 ± 0.58	0.001
Walking at %30 above PWS-2nd min.	9.86 ± 3.33	6.67 ± 1.57	0.001
Walking at %30 above PWS-4th min.	10.31 ± 3.92	7.17 ± 2.13	0.001
Walking at %30 above PWS-7th min.	10.77 ± 4.15	7.27 ± 2.26	0.001

PWS: Preferred walking speed.

consumption at an appropriate level. Brechter et al. has reported that during free walking, there was no significant difference in the peak patellofemoral joint stress between the PFPS group and the control group. However, during fast walking, peak patellofemoral

joint stress was found to be significantly greater in the PFPS group when compared with the healthy controls.²⁷ Powers and colleagues reported that knee kinematics of patients with PFPS during walking at PWS did not differ significantly from healthy controls. But additional kinematic compensation mechanism at knee joint were prominent at faster speed. These changes show the increased external forces acting on the lower extremity during faster walking speeds.²⁸ Findings of these studies may help to explain why energy expenditure was higher in PFPS group during walking at speed %30 above PWS. Although the mean ratings of perceived exertion during both walking speeds are higher than controls, any of patients did not stop walking because of the pain. We aimed to prevent the differences might arise from gender differences in terms of energy consumption by evaluating the net oxygen consumption of participants. While joint motion and muscle activation during PWS did not affect net oxygen consumption significantly, but significant difference occurred in net oxygen consumption during walking at

Table 5

Plantar pressure data of groups and symptomatic and nonsymptomatic extremities in PFPS group.

		PFPS Mean (SD)	Control Mean (SD)	P	Symptomatic Leg Mean (SD)	Nonsymptomatic Leg Mean (SD)	p
Contact area percentage (%)	Rearfoot	21.63 ± 1.93	21.80 ± 1.23	0.654	21.63 ± 1.93	21.21 ± 2.15	0.372
	Midfoot	24.11 ± 3.96	24.53 ± 2.37	0.979	24.11 ± 3.96	25.13 ± 3.84	0.171
	Forefoot	54.33 ± 3.14	53.67 ± 2.51	0.401	54.33 ± 3.14	53.66 ± 3.41	0.200
Peak pressure (N/cm ²)	Medial forefoot	12.42 ± 7.13	13.15 ± 5.87	0.328	12.42 ± 7.13	11.84 ± 6.80	0.688
	Central forefoot	27.13 ± 6.33	25.08 ± 5.97	0.188	27.13 ± 6.33	27.15 ± 6.41	0.806
	Lateral forefoot	14.03 ± 7.30	11.29 ± 5.91	0.092	14.03 ± 7.30	15.34 ± 7.93	0.351
	Midfoot	5.75 ± 2.43	5.70 ± 1.88	0.926	5.75 ± 2.43	6.33 ± 2.29	0.145
	Medial rearfoot	24.06 ± 6.04	22.13 ± 4.21	0.109	24.06 ± 6.04	23.62 ± 5.69	0.505
	Lateral rearfoot	21.33 ± 5.22	19.75 ± 4.76	0.176	21.33 ± 5.22	21.05 ± 4.89	0.563
Impulse (Ns/cm ²)	Medial forefoot	2.73 ± 1.43	2.91 ± 1.41	0.490	12.42 ± 7.13	11.84 ± 6.80	0.688
	Central forefoot	7.14 ± 2.25	6.55 ± 1.77	0.416	27.13 ± 6.33	27.15 ± 6.41	0.806
	Lateral forefoot	4.13 ± 2.51	3.35 ± 1.93	0.214	14.03 ± 7.30	15.34 ± 7.93	0.351
	Midfoot	1.30 ± 0.67	1.27 ± 0.59	0.987	5.75 ± 2.43	6.33 ± 2.29	0.145
	Medial rearfoot	4.99 ± 1.92	4.35 ± 1.16	0.186	24.06 ± 6.04	23.62 ± 5.69	0.505
	Lateral rearfoot	4.42 ± 1.72	3.89 ± 1.13	0.117	21.33 ± 5.22	21.05 ± 4.89	0.563

speed of 30% above PWS. This may indicate that changes that occur with speed increment has reflected in oxygen consumption in the patient group.

Knee flexion angle was found to be significantly reduced in symptomatic knees compared to the nonsymptomatic extremity in PFPS group, and it was also lower in PFPS group than control group in this study. Dorsiflexion, eversion and inversion angle of ankle were lower in PFPS group. However, these differences may be ignored from clinical point of view.

We did not find any significant difference in terms of pedobarography measurements between 2 groups. In addition, PWS may not force subjects well enough to observe significant variation in pedobarography data, as does the walking energy expenditure. PFPS subjects compensate over the adverse effects of PFPS and preserve their normal walking pattern during walking in PWS. However, we have hypothesized that we probably see a more significant difference in terms of pedobarographic measurements, if subjects are asked to walk in 30% higher than PWS.

Some studies in the literature have reported that the walking speed could influence the plantar pressure distribution.^{29–31} Segal et al have investigated the relationship between the walking speed and plantar pressures at different plantar regions on a treadmill during 6 walking speed trials. At faster speeds, the highest pressures were recorded in the hallux and heel regions which also have increased linearly.²⁹ In another study, Chung et al have used 4 different walking and have found that increased walking speed lead a significant increase in peak pressure beneath the big toe, MFF, and HL areas.²⁰ The effects of walking speed on plantar pressure are considered, it can be speculated that the effects of walking speed on plantar pressure were minimized by using PWS in our study.

Powers et al have stated that patients with PFPS had lower ground reaction forces during walking and Brechter & Powers who have indicated that patients with PFPS had less knee extensor moment than controls.^{27,28} According to these studies, patellofemoral joint reaction forces may reduce by imposing less weight on the symptomatic knee to reduce the knee pain especially during walking at faster speed.^{27,28} Weight loading on patellofemoral joint increases patellofemoral dysfunction due to the normal physiological imposes, overuse and intensive training may cause pain.¹⁰ Our findings did not match with the above mentioned studies as the patients with PFPS have demonstrated mostly medial and lateral distribution and there were any significant difference have found in plantar pressures of all plantar regions between 2 groups. Our findings about plantar pressure suggests that because of the walking speed could influence the plantar pressure distribution and being young and physically active patients, PFPS do not exactly affect to plantar loading characteristics to compensate the symptoms during walking at PWS. However, Bek et al have also found any significant changes between groups in terms of plantar pressure parameters, and they have concluded as lower extremity with malalignment or PFPS might adversely affect the non-symptomatic knee mechanics.³² This statement also supports our finding as having no significant difference between symptomatic and non-symptomatic knee in plantar pressure parameters.

The results of our study have shown that the most excessive pain occurred at prolonged sitting and followed by squatting, ascending and descending stairs and during walking. Minimal pain was recorded during resting. This can be explained by the patellofemoral reaction forces that increase during activities like prolonged sitting, stair or slope ascend/descend, or squat which causes an increment in the flexion of knee joint due to the effect of body weight.^{4,33,34} PFPS patients with high intensity pain had low functional level which pointed that severity of pain affects functionality of subjects negatively. During treatment or rehabilitation

processes, increment in the functionality of subjects would be ensured by avoiding pain and optimized muscle use.³⁵

The pain symptom in PFPS may force patient to restrict his/her physical activities. Barton et al have reported that there were no significant difference between PFPS and control group in terms of the average weekly physical activity levels determined by IPAQ. Average weekly physical activity levels of subjects in our study was found to be higher in control group. Since the PFPS is related to stress loading on patellofemoral joint, the limitation of physical activities is inevitable. IPAQ findings of our study seem to confirm that individuals with PFPS limit their physical activity due to the pain.³⁶

As a limitation of our study that the plantar pressure distribution during walking at 30% above PWS could not be performed since subjects were not able to walk at this constant speed. Lastly, patellofemoral pain at different positions during daily life was questioned, but pain during walking at two speed could have been scored with VAS and association between pain scores and energy consumption findings could have been investigated.

In conclusion, PFPS has negatively affected to physical activity levels of PFPS group because of the pain. Although rates of perceived exertion during at both walking condition were higher in patients with PFPS than controls, changes during the fast walking might be lead to an increase of energy consumption. Using PWS provide an advantage for normalizing individual differences and eliminates the effects of walking speed on plantar pressure distribution. The present findings about plantar pressure suggests that young and physically active patients with PFPS do not dramatically change plantar loading characteristics to compensate the symptoms.

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Conflict of interest disclosure

None.

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