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Spinal range of motion and plantar pressure in sport climbers

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Abstract

Purpose: The aim of the study was to investigate the range of motion (ROM) of lumbar and thoracic articulations and static and dynamic plantar pressure in sport climbing athletes.

Methods: The sample included 30 sport climbers with a minimum of 2 years training experience and 30 physical education students who served as an active untrained control. ROM was assessed by a Saunders digital inclinometer; plantar pressure by a baropodometric platform.

Results: Mean spinal ROMs were greater in the sport climbers with the exception of extension, rotation, and lateral thoracic flexion, with a high degree of statistical significance obtained in the majority of the analyzed ROMs. The climbers exhibited increased mean forefoot pressure (smaller rearfoot pressure) in both the dominant and non-dominant extremities, with significant intergroup differences found in dominant forefoot/rearfoot pressure distribution.

Conclusions: Sport climbers present increased lumbar and thoracic ROM, and the characteristics of climbing may also affect transverse arch structure and plantar pressure distribution.

Key words: sport climbing, spinal range of motion, feet

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Introduction

Rock climbing and its popular modality sport climbing belong to a family of disciplines that subject the vertebral column to extreme articulation while extraordinary loads are placed on the distal extremities. There is evidence that rock climbing influences segmental spinal curvature and modifies the longitudinal and transverse arch structures [1],[2]. These changes are credited to the intricacies of climbing, where the upper extremities are used to maintain balance while the center of gravity is held within a supporting plane that allows the climber to execute a subsequent climbing move [3],[4]. In an optimal climbing position, the center of gravity should be directed over the lower extremities to provide a point of support. Of importance is proper hip alignment so that the center of gravity falls between the feet, bringing the body into balance while perched on a cliff or wall [4]. The use of climbing footwear, in turn, forces the foot into a specific curved shape allowing the climber to place greater load on the toes and forefoot [2]. Furthermore, the need to hold the upper arms in a constant superior position is believed to stretch the stabilizing shoulder muscles and shorten the pectoralis muscles, resulting in increased thoracic kyphosis [5]. There are also indications of abnormal cervical lordosis, which may be linked with how a belayer holds the head in a continual extension while securing their partner [5]. In order to further elucidate the biomechanical effects of rock climbing on spine and foot structure, the aim of the study was to investigate spinal range of motion (ROM) in various anatomical planes and plantar pressure distribution in individuals training sport climbing.

Materials and methods

Sixty individuals were recruited, of which 30 were sport climbers with a minimum of 2 years training experience (Group 1) and 30 physical education students not involved in professional or competitive sport (Group 2). Inclusion criteria were age (above 21 but below 35 years of age) and a lack of musculoskeletal injury. Participation was on a voluntary basis and written consent was obtained after the study purpose and procedures were explained. The demographic and anthropometric characteristics of the sample are presented in Table 1. The study was performed at local climbing gyms and in laboratory settings. Approval was obtained from the Senate Ethics Committee for Scientific Research of the University of Physical Education in Wrocław, Poland.

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Table 1. Descriptive statistics of the study participants.

Spinal ROM was assessed in the thoracic and lumbar regions for all relevant anatomical planes with a Saunders digital inclinometer [6]. Measurements were performed in accordance with the guidelines of the manufacturer and American Medical Association [7]. Czaprowski et al. recommended that spinal measurements with the Saunderes inclinometer be taken by one examiner to ensure high repeatability, with intra-observer measurement error found to range from 2.8° to 3.8° [8].

fig.1. The measurement of sagittal, frontal and transverse thoracic and lumbar spine (Saunders) [6].

The next procedure involved measurement of plantar pressure using a FreeMed baropodometric platform integrated with FreeStep software for data processing and analysis [9]. Leg dominance was determined according to the tests described by Bogdanowicz [10]. Forefoot/rearfoot plantar pressure ratio (R/F), as the percentage distribution of load on the forefoot and rearfoot, was computed in static and dynamic conditions. Dynamic medial and lateral plantar pressures were also calculated. Gait analysis was performed to determine foot pronation by following the center of pressure gait line [11].

Statistical analysis was performed with Statistica PL 12.0 software (Statsoft). All data were calculated as means ($\bar{x}$) and standard deviations (*SD*). The normality of the data set was verified using the Shapiro–Wilk normality test. A normal distribution was confirmed, and intergroup comparisons were performed with Student's *t* test. The results were considered statistically significant if $p \leq 0.05$.

Results

Mean spinal ROMs in the lumbar and thoracic flexions were greater in the sport climbers, although below normal ROMs were observed in the lumbar and thoracic extensions and the right and left lateral thoracic flexions. Highly significant differences between both groups were obtained in the majority of the analyzed ROMs (Tab.2).

Table 2. Descriptive and parametric statistics of all ROMs at the thoracic, lumbar, and thoracolumbar segments for the climbers (Group1) and controls (Group 2).

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The climbers exhibited increased mean forefoot plantar pressure in both the dominant and non-dominant extremities in static conditions. The only significant difference between the climber and control groups was in dominant forefoot and rearfoot pressure distribution (Tab.3).

Table 3. Descriptive and parametric statistics of static forefoot and rearfoot plantar pressure distribution for the climbers (Group1) and controls (Group 2).

For dynamic plantar pressure, forefoot and rearfoot distributions were similar in both groups, with no significant differences observed (Tab.4).

Table 4. Descriptive and parametric statistics of dynamic forefoot and rearfoot plantar pressure distribution for the climbers (Group1) and controls (Group 2

While the climber group showed greater medial pressures than the control group, no statistically significant differences were observed (Tab.5).

Table 5. Descriptive and parametric statistics of medial and lateral plantar pressure distribution for the climbers (Group1) and controls (Group 2).

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Discussion

One of the most important elements in a clinical assessment of the musculoskeletal system is defining vertebral structure and, in particular, mobility. Among the numerous factors that may influence spinal range of motion are the intensity and type of physical activity one performs [13]. Individuals who regularly participate in climbing subject the body to frequent static overloading and extreme articulation, affecting tendons, ligaments, and capsules that may lead to modifications of spinal curvature and also range of motion [5]. For the latter effect, we observed significantly greater spinal ROM in lumbar and thoracic flexion but reduced extension ROM in climbers compared with a group of active yet untrained controls. The inherent movement pattern in climbing may explain these findings, as the strong hip flexion is conjugated with pelvic retroversion, which may in turn reduce both lumbar lordosis and ROM during extension movements [14]. The limited ROM in this segment may also be attributed to strong abdominal musculature [15] as well as the development of the “climber's back”, characterized by increased cervical lordosis and thoracic kyphosis. The postural examinations by Kiełt et al. indicated that the “climber's back” is a postural adaption that is strongly correlated with climbing ability, concluding that the higher the climbing level the more exaggerated thoracic kyphotic curvature [5]. Rokowski and Staszkiewicz reported that successful climbing performance (in completing routes) requires a “strong hook”, itself the result of significant upper extremity muscle tension [16]. In turn, the limited lumbar spine extension we observed in the control group may be due to a sedentary lifestyle [17]- [19]. Of interest is the fact that the ROMs of lateral flexion were almost identical between the right and left sides. A similar result was obtained by Starosta, lending to the argument that sport climbing is a symmetric physical activity composed of alternating body movements [20]. While the literature is rich with studies on plantar structure and associated biomechanical and gait analyses, there is a lack of data on the effects of training adaptations across different sports. For example, the greater forefoot plantar pressure we observed in the group of climbers during static conditions may be associated with the use of climbing shoes. By integrating a large arch (downturn) and asymmetrical shape, these types of shoes force the foot into a very specific shape in which body weight is directed entirely over the toes and forefoot. In this way, climbers automatically transfer their entire weight on the forefoot in order to maintain their center of gravity within the supporting plane provided by this part of the foot [19]. In our analysis of the plantar pressure distribution during dynamic conditions, we found that the climbers presented greater medial pressure than the control group. This finding is congruent to what was observed during gait analysis, in which the climbers were observed with reduced pronation when walking. This may be associated with the tendency that less pronation is present in those with higher arch heights [2], [21]. One of the reasons underlying change in the foot arch structure and forefoot pressure of climbers may be through the use of tight (sized two times too small) and highly asymmetric climbing shoes. Attention was also drawn to the fact that the downturn of the shoe places pressure on the toes while unloading the head of the first metatarsus bone and externally rotating the foot. This has been credited with weakening the peroneus longus muscles, which are responsible for pressing the first metatarsus bone towards the ground [2]. According to Schöffl and Küpper, the feet of climbers are subject to considerable pronation during climbing [22]. The increased focus on the deformative effects of climbing footwear, such as by using lateral x-rays, has found that they do not enable normal weight distribution on the first and fifth metatarsal heads and heel, and that plantar flexion at the metatarsal heads leads to the development of plantar fasciitis [22]. The high prevalence of foot deformities and injuries amongst high-level climbers has been credited to the common practice of using too small shoes. In addition, 80–90% of climbers reported pain when using climbing shoes, although this was considered to be an acceptable inconvenience for improved climbing performance [23],[24].

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Conclusion

Sport climbers present increased spinal ROM in the majority of the anatomical planes and the characteristics of climbing may also affect transverse arch structure and plantar pressure distribution.

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Table 1. Descriptive statistics of the study participants.

	Group 1			Group 2		
	$\bar{x} \pm SD$	Min	Max	$\bar{x} \pm SD$	Min	Max
Age	28.13 ± 3.61	21	25	24.5 ± 2.76	21	35
Body height [cm]	174.1 ± 8.13	156	187	171.1 ± 9.16	155	185
Body mass [kg]	65.9 ± 11.5	49	86	67.5 ± 12.5	49	86
BMI	21.6 ± 2.22	17.9	26.2	22.9 ± 2.39	18.5	29.1

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Table 2. Descriptive and parametric statistics of all ROMs at the thoracic, lumbar, and thoracolumbar segments for the climbers (Group1) and controls (Group 2).

	Normal	Group 1		Group 2		Group 1–Group 2	
Variable	ROM	$\bar{x}$	*SD*	$\bar{x}$	*SD*	*t*	*P*
BF-AF	60	60.53	4.55	51.43	5.28	7.15	0.000***
BE-AE	25	21.33	3.71	21.60	2.43	−0.33	0.743
BR-AR	20–30	28.77	5.24	21.77	2.27	6.71	0.000***
BL-AL	20–30	28.20	4.54	21.03	3.06	7.18	0.000***
RBR-AR	5–10	8.70	3.68	8.53	2.18	0.21	0.832
RBL-AL	5–10	8.53	3.12	8.93	1.78	−0.61	0.544
CF-BF	20–30	31.63	4.19	22.60	2.63	9.99	0.000***
CE-BE	20–35	17.63	2.31	27.33	1.94	−17.62	0.000***
CR-BR	20-30	16.63	3.47	25.70	1.66	−12.91	0.000***
CL-BL	20–30	16.97	3.59	25.33	1.71	−11.54	0.000***
RCR-BR	20–30	34.20	8.06	34.67	6.89	−0.24	0.810
RCL-BL	20–30	33.87	8.02	33.13	7.43	0.37	0.715

*** $p \leq 0.001$; BF-AF – lumbar flexion, BE-AE – lumbar extension, BR-AR – right lumbar flexion, BL-AL – left lumbar flexion, RBR-AR – right lumbar rotation, RBL-AL – left lumbar rotation, CF-BF – thoracic flexion, CE-BE – thoracic extension, CR-BR – right lateral thoracic flexion, CL-BL – left lateral thoracic flexion, RCR-BR - right thoracic rotation, RCL-BL – left thoracic rotation

Table 3. Descriptive and parametric statistics of static forefoot and rearfoot plantar pressure distribution for the climbers (Group1) and controls (Group 2)

Variable	Group 1		Group 2		Group 1–Group 2	
	x̄	SD	x̄	SD	t	p
DOM FORE	55.57	10.66	47.40	12.05	2.78	0.007*
DOM REAR	44.43	10.66	52.60	12.05	−2.78	0.007*
NON FORE	54.70	9.96	50.57	12.01	1.45	0.152
NON REAR	45.30	9.96	49.43	12.01	−1.45	0.152

*$p \leq 0.05$; DOM FORE – dominant extremity forefoot plantar pressure distribution, DOM REAR – dominant extremity rearfoot plantar pressure distribution, NON FORE – non-dominant extremity forefoot plantar pressure distribution, NON REAR – non-dominant extremity rearfoot plantar pressure distribution

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Table 4. Descriptive and parametric statistics of dynamic forefoot and rearfoot plantar pressure distribution for the climbers (Group1) and controls (Group 2)

Variable	Group 1		Group 2		Group 1–Group 2	
	$\bar{x}$	*SD*	$\bar{x}$	*SD*	*t*	*p*
DOM	57.63	6.82	57.20	6.76	0.25	0.806
DOM	42.37	6.82	42.80	6.76	−0.25	0.806
NON	58.57	6.86	59.93	6.21	−0.81	0.422
NON	41.43	6.86	40.07	6.21	0.81	0.422

DOM FORE – dominant extremity forefoot plantar pressure distribution, DOM REAR – dominant extremity rearfoot plantar pressure distribution, NON FORE – non-dominant extremity forefoot plantar pressure distribution, NON REAR – non-dominant extremity rearfoot plantar pressure distribution

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Table 5. Descriptive and parametric statistics of medial and lateral plantar pressure distribution for the climbers (Group1) and controls (Group 2).

Variable	Group 1		Group 2		Group 1–Group 2	
	$\bar{x}$	*SD*	$\bar{x}$	*SD*	*t*	*p*
DOM MED	48.17	5.91	46.60	6.96	0.94	0.351
DOM LAT	51.83	5.91	53.07	6.92	−0.74	0.461
NON MED	49.13	5.77	46.83	6.39	1.46	0.149
NON LAT	50.87	5.77	53.17	6.39	−1.46	0.149

DOM MED – dominant extremity medial plantar pressure, DOM LAT – dominant extremity lateral plantar pressure, NON MED – non-dominant extremity medial plantar pressure, NON LAT – non-dominant extremity lateral plantar pressure

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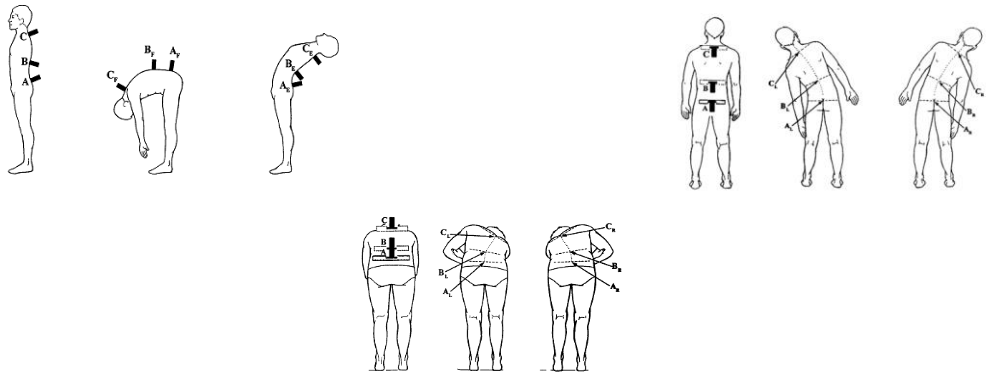

fig.1. The measurement of sagittal, frontal and transverse thoracic and lumbar spine (Saunders) [6].

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