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AN EXPLORATION OF KNEE JOINT ANGLES AND MOMENTS ON DIFFERENT STEPS DURING STAIR ASCENT AND DESCENT AND THEIR IMPLICATIONS TO FUNCTIONAL DEMAND

***Ana Luiza Costa e Silva Cabral*[1], *Johan Robalino*[1], *Victor Hugo Vilarinho Carrijo*[1], *Pedro Fonseca*[1], *Jim Richards*[2], *João Paulo Vilas-Boas*[1]**

[1] *Porto Biomechanics Laboratory (LABIOMEP), CIFI2D, Faculty of Sport, University of Porto, Portugal.*

[2] *Allied Health Research unit, University of Central Lancashire, UK.*

analuizacsc@gmail.com; johanrobalino@gmail.com; vilarinhovictorh@gmail.com; pedro.labiomep@fade.up.pt; JRichards@uclan.ac.uk; jpvb@fade.up.pt

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1 INTRODUCTION

Ascending and descending stairs is a challenging task for the musculoskeletal system[1], since it requires a higher demand on the lower limbs due to unipedal support[2,3], compared to walking. The differences in knee movement patterns between stair ascent and descent, when compared to walking, are substantial and well described in the literature[2,3]. However, little is known about the differences between the steps during an entire ascending or descending cycle. Therefore, the aim of this study was to analyze knee joint angles and moments during stair ascent-descent comparing each step.

2 METHODS

Eighteen healthy individuals (10 female, 8 male), 29.3±4.7 years old, height of 1.67 ± 0.08, and weight of 67.9 ± 12.2 kg participated in this study. This cross-sectional study was approved by the ethics committee of Faculty of Sport from University of Porto and all volunteers signed an informed consent form. Kinematic data were recorded using eight Miqus Video cameras (Qualisys AB, Sweden), operating at 100 Hz, and processed in Theia software (Theia Markerless, Canada) to obtain a three-dimensional (3D) biomechanical model, from which the angular kinematics and kinetics in the sagittal plane were studied. Kinetic data was recorded with a four-step staircase with a force platform embedded on each step (two Bertec, OH, USA and two AMTI, MA, USA) sampling at 2000 Hz. The steps had a riser height of 17 cm, run of 25 cm, and width of 60 cm. Participants were instructed to perform five repetitions of stair ascent and descent at a self-selected pace. Each task began with the participant at rest in front of the first step (ground for ascending or top platform for descending) and ended on the last step (top platform for ascending or ground for descending), standing still and looking straight ahead. The movement was initiated with the non-dominant lower limb. Data were processed in Visual3D (HAS-Motion, Canada) and a fourth-order Butterworth low pass filter with cut-off frequency of 6 Hz was applied for kinematic data. Knee joint moments were calculated using 3D inverse dynamics. Further analysis was performed in Matlab (The MathWorks Inc., USA) and were analyzed for each task (ascent and descent) and each step contact (steps 1, 2, 3 for ascending and steps 3, 2, 1 for descending). Knee joint moment data were then normalized to body mass. The average of five repetitions of the three central steps was used for analysis. Data analysis was performed using SPSS version 29 (IBM, USA). A two-factor Repeated Measures ANOVA test (three steps, ascent/descent tasks) was used to compare the three steps during ascent and descent. When p-value was less than 0.05, the Bonferroni test was used for pairwise comparisons between steps with a significance value of $p<0.05$.

3 RESULTS AND DISCUSSION

The results for knee angles and moments are presented in Table 1 and 2, respectively, during stair (Step) ascent and descent (Task).

Table 1. Knee angles in sagittal plane expressed as mean and standard deviation during ascent and descent stairs.

Variables		Step 1	Step 2	Step 3	P value - Task	P value - Step
Maximum flexion (º)	ASC	69.36 (4.15)	70.17 (3.06)	72.06 (3.99)	<.001*	<.001*
	DES	91.03 (5.02)	91.85 (4.41)	94.47 (4.28)		
Maximum extension (º)	ASC	7.80 (3.48)	6.13 (3.67)	8.15 (3.66)	0.287	0.07
	DES	7.55 (2.93)	8.53 (3.16)	8.48 (3.23)		
Range of motion (º)	ASC	61.55 (5.69)	64.03 (5.21)	63.90 (6.14)	<.001*	0.01*
	DES	85.98 (4.57)	83.31 (4.89)	83.47 (5.93)		

º: degrees; s: seconds; *: p<0.005 from two-factor ANOVA.

Significant differences were seen between Tasks and Steps for maximum flexion and range of motion with descent showing greater values. Post hoc comparisons during ascent showed, maximum knee flexion angle was higher in step 3 compared to step 1 ($p<0.001$), and in step 3 compared to step 2 ($p=0.012$). Furthermore, the range of motion of the knee was higher in step 3 compared to step 1 ($p=0.001$). During descent, maximum knee flexion angle was higher in step 3 compared to step 1 ($p<0.001$), and in step 3 compared to step 2 ($p=0.013$). Knee range of motion was higher in step 1 compared to step 3 ($p=0.005$) and in step 3 compared to step 2 ($p=0.008$).

Table 2. Knee moments in sagittal plane expressed as mean and standard deviation.

Variables		Step 1	Step 2	Step 3	P value - Task	P value - Step
Maximum flexion moment (N·m/kg)	ASC	1.11 (0.24)	1.00 (0.28)	1.10 (0.24)	0.13	<.001*
	DES	1.20 (0.14)	1.00 (0.20)	1.18 (0.16)		
Maximum extension moment (N·m/kg)	ASC	- 0.43 (0.13)	-0.45 (0.14)	-0.38 (0.14)	<.001*	0.046*
	DES	-0.12 (0.05)	-0.14 (0.08)	-0.12 (0.05)		
Range of flexion extension moment (N·m/kg)	ASC	1.54 (0.27)	1.46 (0.31)	1.48 (0.30)	<.001*	<.001*
	DES	1.32 (0.14)	1.14 (0.19)	1.31 (0.17)		
Contact time (s)	ASC	0.92 (0.08)	0.87 (0.09)	0.94 (0.08)	0.001*	0.001*
	DES	0.83 (0.06)	0.78 (0.07)	0.83 (0.08)		

N·m/kg: Newtons meter per kilogram; s: seconds; *: p<0.005 from two-factor ANOVA.

Significant differences were seen between Task for maximum extension moment and range of flexion extension moment with ascent showing greater values and Step for maximum flexion moment, maximum extension moment and range of flexion extension moment ($p<0.05$). Post hoc comparisons showed that during ascent knee maximum flexion moment was higher in step 1 compared to step 2 ($p=0.025$), and in step 3 compared to step 2 ($p=0.039$). Knee maximum extension moment was also higher in step 3 compared to step 1 ($p=0.027$). During descent, knee maximum flexion moment was higher in step 1 compared to step 2 ($p<0.001$) and in step 3 compared to step 2 ($p=0.002$). Range of flexion extension moment was higher in step 1 compared to step 2 ($p<0.001$) and in step 3 compared to step 2 ($p=0.002$). Contact time was higher in step 1 compared to step 2 during ascent ($p=0.001$) and during the descent ($p<0.001$). In addition, contact time was higher in step 3 compared to step 2 during ascent ($p<0.001$) and during descent ($p<0.001$). Many studies have shown changes in performance during stair ascending and descending in individuals with lower limb pathologies[1] and older adults[2], but little has been done on the differences in demand between each step of the ascending and descending cycle.

4 CONCLUSIONS

Our results suggest that each step during an entire ascending and descending cycle has different demands on knee angles and moments. These differences affect the estimation of functional demand on the knee which could be important when considering the functionality of individuals with pathologies and the elderly.

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