

Estimation of upper-body joint moments in climbing training tasks

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Summary

Musculoskeletal simulations were used to assess joint moments during overhead dynamic exercises in climbing training. Understanding the mechanical loading of the upper body during training tasks is crucial for performance optimization and injury prevention [1]. This study aims to quantify and compare shoulder and elbow joint loads in three training exercises: pull-ups, dynamic campus moves, and static campus moves. The body kinematics were collected with marker-based 3D motion capture, and the joint moments were calculated using OpenSim. The observed joint moments during a pull-up are lower compared to campus tasks. The highest moments appear in the supporting hand during the reaching phase in the static condition.

Introduction

Competitive climbing has evolved significantly [2]. One important aspect for general sports sciences is mechanical loading, which can either lead to physiological adaptations from training, or potential chronic overload injuries and therefore impact sport performance and function of the musculoskeletal system [3], [4].

Methods

A total of 29 recreational male and female climbers (age: 26.0 ± 5.0 years; climbing experience: 9.7 ± 6.2 years; height: 1.8 ± 0.1 m; weight: 68.1 ± 10.5 kg; BMI: 22.1 ± 2.3 and arm span: 1.8 ± 0.1 m) were included in the study. The exercises were carried out on horizontal wooden rungs with implemented force sensors. The force signal was processed by a Butterworth 4th order 20 Hz lowpass filter. With the motion capture data, musculoskeletal simulations were performed in OpenSim and statistical analyses were conducted to compare joint loading patterns. This paper verifies the hypothesis that the shoulder joint moments show a higher magnitude than the elbow joint moments. Furthermore, joint loads of the supporting hand in static trials are expected to be higher compared to dynamic trials.

Results and Discussion

The joint moments in shoulder extension/flexion of the supporting hand in the pulling phase, before the reaching hand leaves the lower hold, is higher in both static (0.139 ± 0.025 Nm/N) and dynamic (0.138 ± 0.020 Nm/N) trials compared to pull-ups (0.112 ± 0.019 Nm/N) which was also shown statistically by the Mann-Whitney U tests. This high flexion moment in static trials is caused by a weight shift towards the supporting hand, to get the bodyweight closer to the fulcrum and prepare for the reaching hand to let go of the hold. In the reaching phase, where the reaching hand catches the upper hold, the static supporting hand has significantly higher values ($U=266.000$, $Z=-2.403$, $p=0.016$, 0.160 ± 0.036 Nm/N) compared to dynamic one. In contrast, in dynamic trials in the pulling phase, the reaching hand experiences higher shoulder extension/flexion joint moments than the supporting hand ($U=248.000$, $Z=-2.683$, $p=0.007$).

Pulling phase	Mean joint moments [Nm/N]				
	pullup	static, supporting hand	static, reaching hand	dynamic, supporting hand	dynamic, reaching hand
Shoulder adduction/abduction	0.063±0.011	0.063±0.016	0.081±0.022	0.065±0.014	0.073±0.017
Shoulder internal/external rotation	0.055±0.015	0.059±0.023	0.049±0.014	0.052±0.018	0.064±0.021
Shoulder extension/flexion	0.112±0.019	0.139±0.025	0.130±0.031	0.138±0.020	0.156±0.022
Elbow extension/flexion	0.048±0.014	0.050±0.022	0.045±0.015	0.042±0.021	0.036±0.014
Elbow pronation/supination	0.004±0.001	0.004±0.002	0.004±0.002	0.003±0.002	0.004±0.002

Reaching phase	Mean joint moments [Nm/N]				
	pullup	static, supporting hand	static, reaching hand	dynamic, supporting hand	dynamic, reaching hand
Shoulder adduction/abduction		0.056±0.017	0.106±0.025	0.050±0.012	0.114±0.019
Shoulder internal/external rotation		0.063±0.026	0.062±0.023	0.050±0.016	0.085±0.028
Shoulder extension/flexion		0.160±0.036	0.113±0.035	0.141±0.026	0.120±0.032
Elbow extension/flexion		0.056±0.018	0.037±0.014	0.046±0.017	0.032±0.011
Elbow pronation/supination		0.005±0.003	0.005±0.002	0.004±0.002	0.007±0.002

Figure 1 Overview of mean joint moments [Nm/N] taken from the maximal joint moments of every participant during the pulling phase of climbing training tasks

The elbow extension/flexion moments show similar behaviour to the shoulder moments, while the magnitudes for shoulder adduction/abduction moments are highest in the reaching phase for the reaching hand, when catching the upper hold. In comparison to the results of joint moments in different static lock-off conditions in Exel et al. [5], the pull-ups show slightly higher moments, and the moments occurring during campus tasks were significantly higher, due to the body mass acceleration.

Conclusion

In the pull-up phase, the joint moments in shoulder extension/flexion are clearly higher for campus trials than pull-ups. In the reaching phase, both shoulder and elbow extension/flexion are higher for the supporting hands than for the reaching hands, especially for static trials. This is led back to the character of a static lock-off, where the supporting hand holds the full bodyweight during the reach-up. However, the shoulder adduction/abduction moments are higher for the reaching hands, with the dynamic reaching hand showing the highest magnitudes, since the velocity during the catch is higher.

References:

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