Reference

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Leg stiffness in unilateral transfemoral amputees across a range of running speeds

Journal of Biomechanics (2019); 84:67-72; DOI: 10.1016/j.jbiomech.2018.12.014

Products

1E90, 1E91, 3S80, 3R95

Major Findings

With *1E90, 1E91, 3S80* and *3R95* comparing affected (prosthetic) limbs to unaffected limbs:

→ **Different leg stiffness regulation strategies for affected and unaffected limbs across running speeds are possibly related to limited force-production capability and mechanical constraints of the affected limb**

→ **Difference of leg stiffness between affected and unaffected limb increases with running speed**

- Leg stiffness in the affected limb decreased with increasing running speed, while remaining unchanged in the unaffected limb (significant interaction effect limb x speed; $p<0.01$)

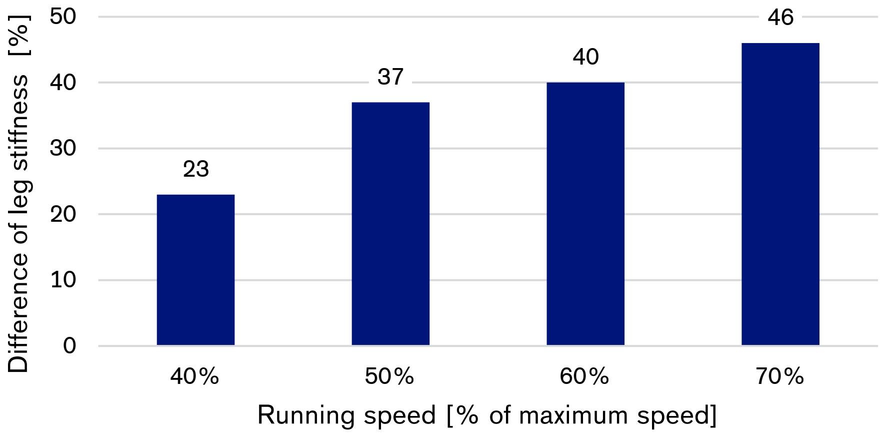


Figure 1. Difference of leg stiffness between affected and unaffected limbs at different running speeds

→ **Lower force production and greater leg compression contribute to reduced spring-like behavior in the affected limbs at higher running speeds**

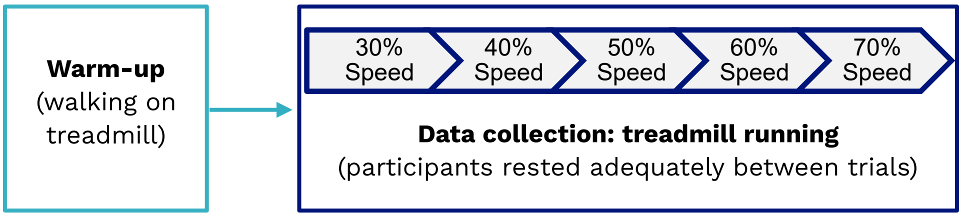
- Lower vertical ground reaction force at 40-70% speed ($p<0.05$)
- Greater peak leg spring compression during ground contact at 50-70% speed ($p<0.05$)
- Lower vertical stiffness at 50-70% speed ($p<0.05$)

Population

Subjects:	9 sprinters (3 female, 6 male)
Amputation level:	unilateral transfemoral
Previous prosthesis:	Knee: 3S80 (8), 3R95 (1); Foot: 1E90 Sprinter (6), 1E91 Runner (2), KATANA-β (1)
Amputation causes:	Trauma (3), Sarcoma (3), Cancer (2), Congenital (1)
Mean age:	28.56 ± 12.42 years
Mean time since amputation:	12.6 ± 9.51 years?
MFCL:	not reported
Record 100m-sprint mean:	17.36 ± 2.36s
Training experience:	>5 years

Study Design

Prospective study design:



Participants completed 5 trials of treadmill running at incremental speeds of their maximum running speed (calculated from their personal record times at 100m-competition races). Each trial consisted of 20s of running at the target speed.

Results

Activities		Participation				Body function			Other
Sprinting, running, jumping	Other sports	Leisure / recreational sports	Competitive sports	Paralympic sports	Preference, satisfaction, QoL	**Biomechanics (kinematics / kinetics)**	Clinical (metabolic / performance)	Medical (pain, injuries)	Technical aspects / alignment

Category	**Outcomes**	**Results for unaffected vs. affected limb**	**Sig.[a,b]**
Biomechanics (kinematics / kinetics)	Leg stiffness k_{leg} * [kN/BW/m]	k_{leg} did not change significantly with speed (main effect).	0
		<u>k_{leg} significantly differed between limbs (main effect):</u> Magnitude of leg stiffness was significantly smaller in the affected limb relative to the unaffected at 40%, 50%, 60% and 70% speed: $k_{leg,affected} < k_{leg,unaffected}$	++
		<u>k_{leg} showed a significant limb x speed interaction:</u>	++
		• Unaffected limb: no significant change in leg stiffness with speed	0
		• Affected limb: k_{leg} decreased as speed increased to 70%. Significant difference in k_{leg} between 30% & 70%, 40% & 70% and 50% & 70% speed.	++
		Magnitude of leg stiffness difference between affected and unaffected limbs increased with increasing speed:	

Running speed [%]	Magnitude of Δ k_{leg} [%]
40	23.0
50	37.1
60	40.2
70	45.6

	Vertical Ground reaction force F_{peak} [BW]	F_{peak} differed significantly across running speeds according to main effect, however subsequent analysis did not find a significant speed effect within the individual limbs.	++ (0)
		<u>F_{peak} differed significantly between affected and unaffected limbs (main effect):</u>	++

Category	Outcomes	Results for unaffected vs. affected limb	Sig.[a,b]
		Affected limb showed reduced peak ground reaction force at 40%, 50%, 60% and 70% speed compared to the unaffected limb.	
		<u>F_{peak} showed a significant interaction of limb x speed:</u> The between-limb difference in F_{peak} was greater at slower speeds than at 70% speed.	++
	Peak leg spring compression during ground contact ΔL [m]	ΔL changed significantly across running speeds (main effect).	++
		<u>ΔL differed significantly between affected and unaffected limbs (main effect):</u> Significantly greater leg compression in the affected limb compared to the unaffected at 50-70% speed: $\Delta L_{affected} < \Delta L_{unaffected}$	++
		<u>ΔL showed a significant interaction of limb x speed:</u> • Affected limb: limb compression increases with speed • Unaffected limb: limb compression did not increase with speed Magnitude of compression difference between the affected and unaffected limbs was greater at 70% speed than at slower speed.	++
	Vertical stiffness k_{vert}** [kN/BW/m]	k_{vert} changed significantly with speed (main effect).	++
		<u>k_{vert} differed significantly between affected and unaffected limbs (main effect):</u> Lower k_{vert} in the affected limb at 50%, 60% and 70% speed: $k_{vert,affected} < k_{vert,unaffected}$	++
		<u>k_{vert} showed a significant limb x speed interaction:</u> • Affected limb: vertical stiffness did not increase with speed • Unaffected limb: k_{leg} increased with faster speed (70%). The difference between 30% & 70%, 40% & 70% and 50% & 70% was significant.	++
	Vertical displacement of the Centre of Mass during ground contact Δy [m]	Overall, Δy significantly changed with speed (main effect). Further testing indicated only a non-significant tendency for Δy to decrease with increasing speed.	++ (+)
		<u>Δy differed significantly between affected and unaffected limbs (main effect):</u> Significantly greater Δy in the affected limb at 50%, 60% and 70%: $\Delta y_{affected} > \Delta y_{unaffected}$	++
		Δy showed no significant limb x speed interaction.	0
		θ increased significantly with speed (main effect).	++
		Θ was not significantly different between limbs (main effect).	0

Category	Outcomes	Results for unaffected vs. affected limb	Sig.[a,b]
	Sweep Angle θ [°] (swept by the leg during ground contact)	θ showed a significant limb x speed interaction: θ increased with increasing running speed in both limbs, but a greater increase was found in the affected limb	++
	Ground contact time t_c [s]	t_c changed significantly with running speed (main effect)	++
		t_c was significantly different between limbs (main effect): Ground contact time was significantly longer in the affected limb than in the unaffected at 50%, 60% and 70% speed: $tc_{affected} > tc_{unaffected}$	++
		t_c showed a significant limb x speed interaction: t_c decreased with increasing running speed in both limbs	++
	Step frequency f_{step} [Hz]	f_{step} increased significantly with increasing speed (main effect).	++
		f_{step} was not significantly different between limbs (main effect).	0
		f_{step} showed no significant limb x speed interaction.	0

[a] no difference (0), positive trend (+), negative trend (–), significant (++/−−), not applicable (n.a.) significance set at $p<0.05$; trends set at $0.1>p>0.05$
[b] effect sizes classified as small (<0.3), moderate (>0.3 and <0.5) or large (>0.5)

* k_{leg} = stiffness of the leg spring = peak vertical GRF divided by peak leg spring compression ($F_{peak}/\Delta L$)

Author's Conclusion

"In summary, the current results indicated that (1) affected limb of unilateral TFA cannot maintain a constant k_{leg} with running at different speeds, and (2) the k_{leg} regulation strategy of unilateral transfemoral amputees was not the same in the affected and unaffected limbs across a range of running speeds. Differences in the k_{leg} regulation strategy during running in unilateral TFAs might be due to the limited force production capability and mechanical constraints of their affected limb. Unilateral TFAs in the present study used different types of prosthetic knees with varied time since amputation, which might indirectly influence the running mechanics (Baum et al., 2013; Noroozi et al., 2014). Thus, caution needs to be taken regarding the interpretation and generalization of these findings." (Hobara et al., 2019)

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