Biomechanical Analysis of the ground reaction force during kick-off on roller skis

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Introduction

Cross country skiing became very popular in Switzerland because of the Olympic success of swiss athletes. However, training opportunities during summer are rare. An alternative training represents the roller skiing, similar to inline skating, where the sport devices consist of two wheels at both ends of a rail. Two poles are additionally used to apply a thrust force. Few literature is available about the loading of roller skis, which makes a designing optimisation of the skis difficult.

The aim of the study was therefore the biomechanical analysis of acting forces on roller skis for different techniques to derive a loading protocol for endurance testing on testing machines.

Fig. 1: Roller skier in three different loading phases during a field test (top) and used roller skis (Skiroll GmbH, Switzerland).

Material & Methods

Tests in the gait laboratory

To determine the ground reaction force applied by the two wheels, a kick-off acceleration was performed in a gait laboratory at the timepoint, when each single wheel was placed on a single force plate. Tests have been performed with a speed of approx. 10 km/h. No poles were used for the tests.

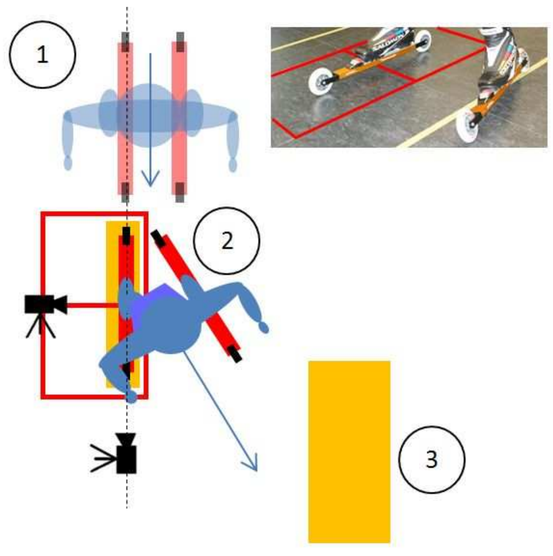


Fig. 2: Measuring the kick-off forces of the front and rear wheel on two force measurement plates. 1. Gliding phase, 2. kick-off acceleration, 3. deceleration by a protective mat.

Field testing

Measurements were taken at full speed under realistic training conditions for three athletes. Strain was measured by strain gauges on the bottom side of the skis, which were then used to calculate material stresses using the young's modulus. The strain gauges were placed at the location, where highest bending stresses were expected. Data acquisition was performed with a mobile system, placed in a backpack of the athletes.

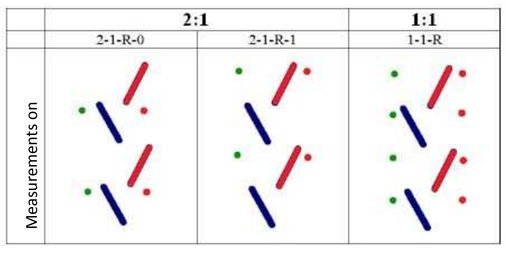


Fig 3: Applied skating techniques 2:1 and 1:1. The right ski and the right pole (in red) were equipped with strain gauges (=R). (Pole thrust for the 2-1-R-0 technique occurred parallel to the left kick-off, therefore = 0).

Experimental testing and FE Analysis

A Finite Elemente Analysis and an experimental test on a testing machine were performed to derive a realistic relationship between the forefoot and rear foot force distribution—by applying similar strain loading protocol measured in the field testing.

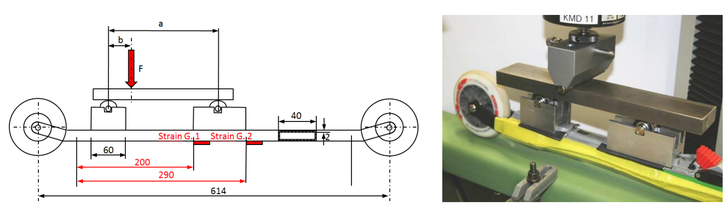


Fig. 4: Strain gauges placed on the bottom side of the skis (left) and load introduction on the testing machine to determine the forefoot and rearfoot loading distribution.

Results

Ground reaction force in the lab test

Total ground reaction force reached a value of 1'500 N under laboratory conditions for an initial speed of 10 km/h. Maximum force peak was reached within 40 ms after the initiation of the kickback (start of force application). Complete lift off of the ski from the force plate was detected after 200 ms.

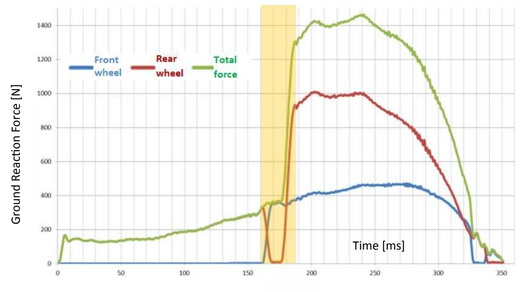


Fig. 5: Vertical ground reaction force on both force plates applied by the rear wheel (red) and front wheel (blue). Data of the strongest athlete).

Results of the field testing

Generally, the pole force reached forces between 150—200 N (one pole). Maximum loading of the skis resulted in bending stresses of 120 MPa in the rear strain gauge.

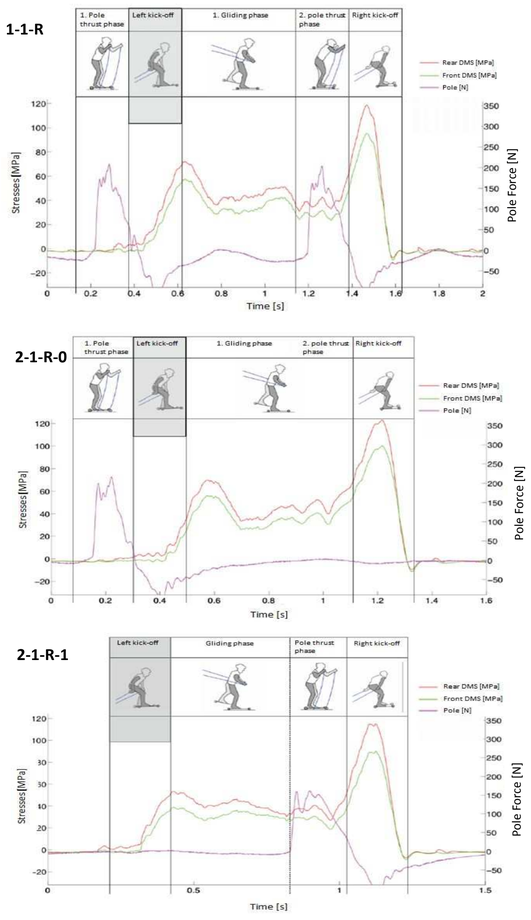
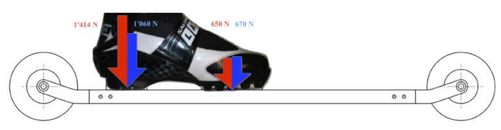


Fig. 6: Applied stresses measured by the strain gauges (in MPa, left y-axis) and pole forces (in N, right y-axis).

Results of the Experimental testing and FEM

By generating the same loading protocol of the strain gauges on the testing machine, the force ratio between fore- and rear foot was determined to be approx. 35% : 65%, which was confirmed by Finite Elemente Analysis.



	Total Force	Force on Rear Foot		Force on Fore Foot	
	[N]	[N]	[%]	[N]	[%]
Computer Model	**2'064**	**1'414**	68.5	**650**	31.5
Experimental Testing	**1'730**	**1'060**	61.3	**670**	38.7

Fig. 7: Force distribution on the fore- and rear foot, evaluated by applying similar loading conditions by the testing machine.

Discussion

Total loading of the force plates under lab conditions reached a value of 1'500 N, whereas in the field test a force of 2'000 N was transferred on one ski. The measured forces allow a definition of a realistic loading scenario to perform fatigue testing of roller skis.

Acknowledgments

We would like to thank Skiroll GmbH, Solothurn, Switzerland, for the technical support in the project.