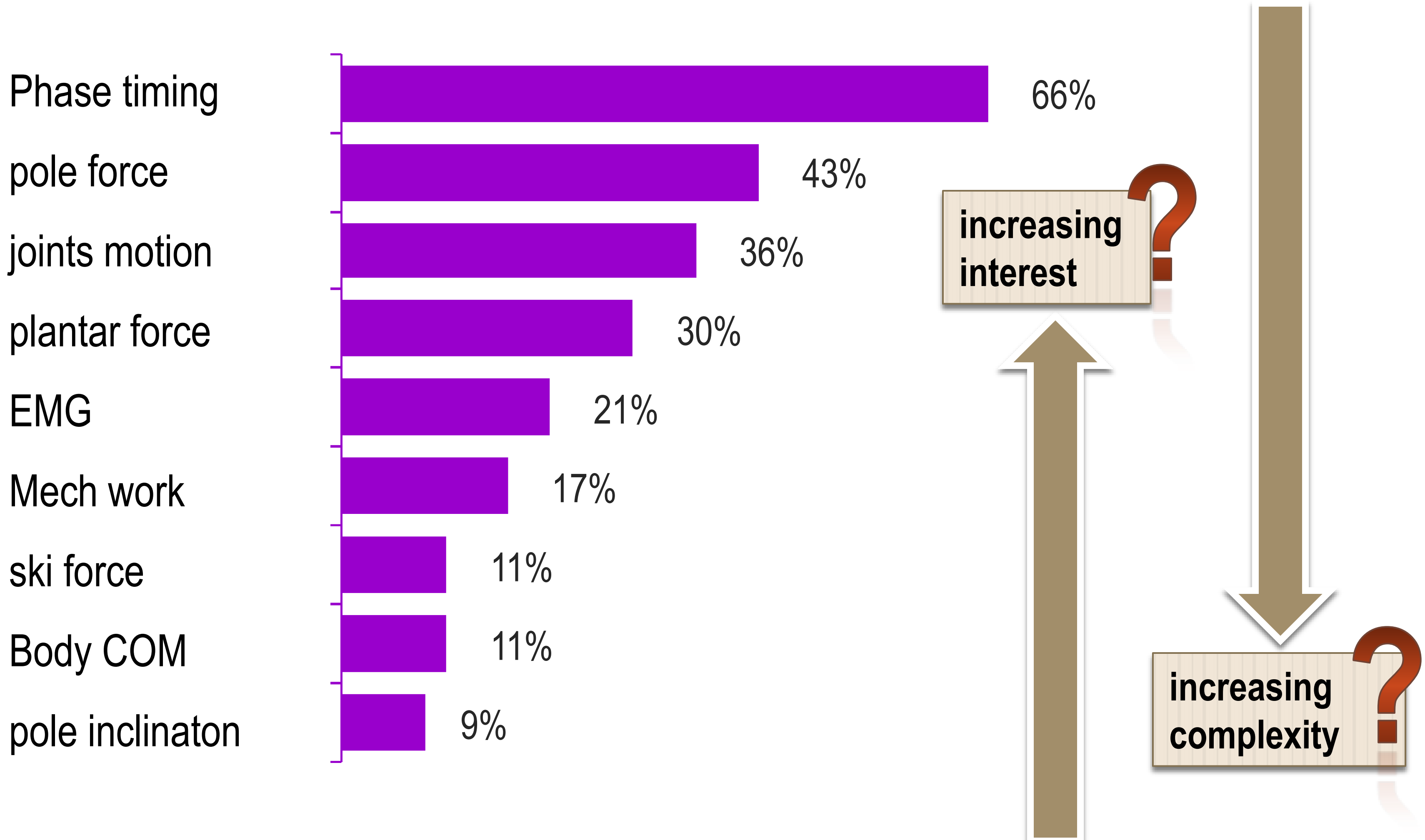
research center - Rovereto (TN)
CeRiSM
sport mountain health

Cross country skiing analyzed from center of mass point of view

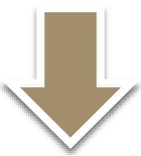
Pellegrini Barbara
Zoppirolli Chiara
Bortolan Lorenzo
Schena Federico

Recent Cross country ski biomechanical studies

Biomechanical studies 2008 -2015 : n 47

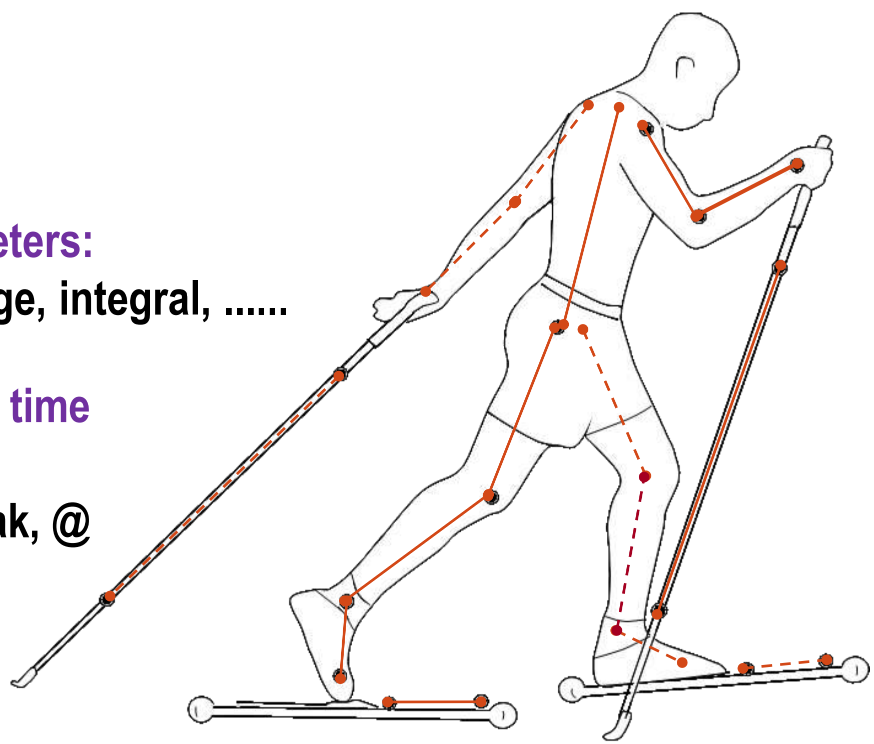


Cross-country skiing biomechanics
..........many segments an parameters to look at!



Different parameters:
Min, max, average, integral, ...

Multiplied by N time instants :
@ CT0%, @Fpeak, @ v min....



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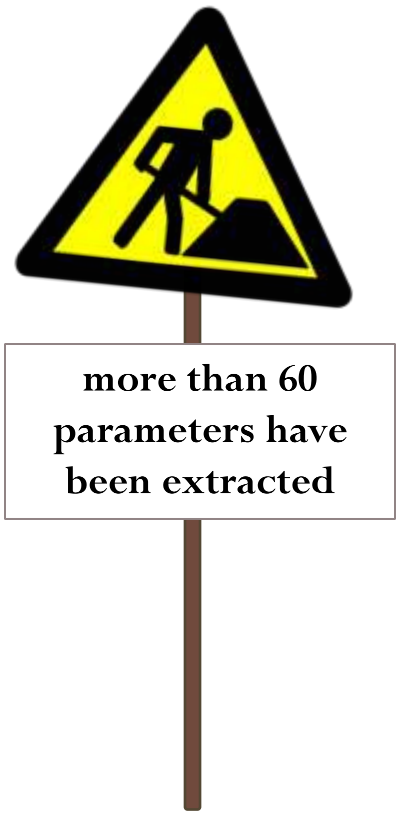
Med. Sci. Sports Exerc., Vol. 37, No. 5, pp. 807–818, 2005

Biomechanical Analysis of Double Poling in Elite Cross-Country Skiers

HANS-CHRISTER HOLMBERG[1,2], STEFAN LINDINGER[3,4], THOMAS STÖGGL[3,4], ERICH EITZLMAIR[3,4], and ERICH MÜLLER[3,4]

EMG on 19 muscles
Pole force
Plantar force
Angle for 4 body joints
.....



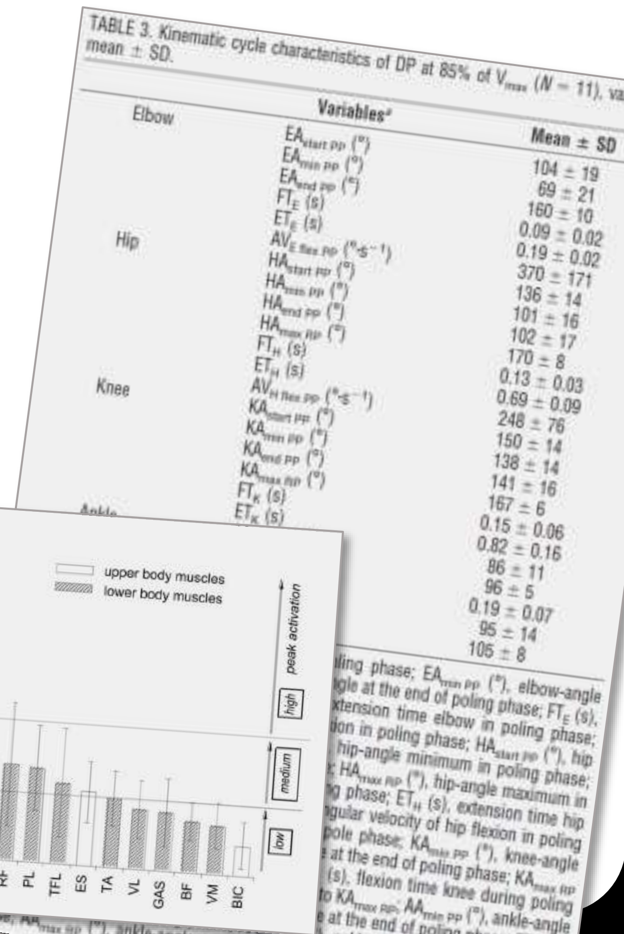
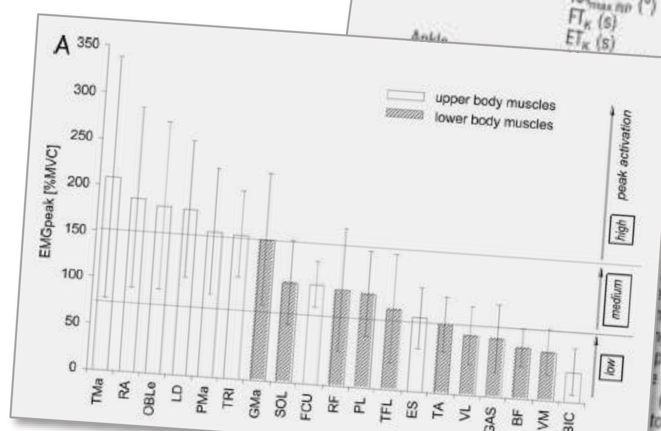


TABLE 3. Kinematic cycle characteristics of DP at 85% of V_{max} (N = 11), values mean ± SD.

	Variables	Mean ± SD
Elbow	$EA_{start\ PP}$ (°)	104 ± 19
	$EA_{min\ PP}$ (°)	69 ± 21
	$EA_{end\ PP}$ (°)	160 ± 10
	FT_E (s)	0.09 ± 0.02
	ET_E (s)	0.19 ± 0.02
Hip	$AV_{E\ flex\ PP}$ (°·s⁻¹)	370 ± 171
	$HA_{start\ PP}$ (°)	136 ± 14
	$HA_{min\ PP}$ (°)	101 ± 16
	$HA_{end\ PP}$ (°)	102 ± 17
	$HA_{max\ RP}$ (°)	170 ± 8
	FT_H (s)	0.13 ± 0.03
	ET_H (s)	0.69 ± 0.09
Knee	$AV_{H\ flex\ PP}$ (°·s⁻¹)	248 ± 76
	$KA_{start\ PP}$ (°)	150 ± 14
	$KA_{min\ PP}$ (°)	138 ± 14
	$KA_{end\ PP}$ (°)	141 ± 16
	$KA_{max\ RP}$ (°)	167 ± 6
	FT_K (s)	0.15 ± 0.06
	ET_K (s)	0.82 ± 0.16
Ankle		86 ± 11
		96 ± 5
		0.19 ± 0.07
		95 ± 14
		105 ± 8



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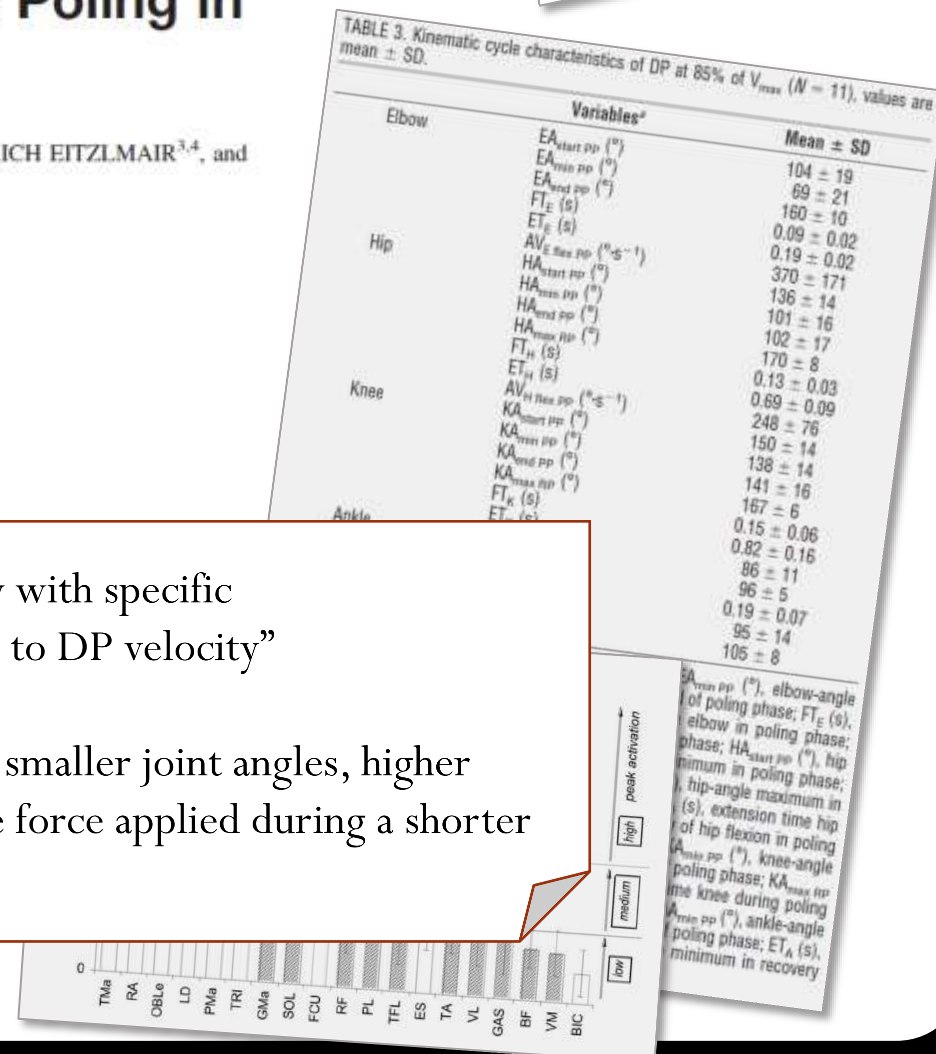

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		95 ± 14
		105 ± 8

"The best skiers use a DP strategy with specific characteristics directly correlated to DP velocity"

"This strategy is characterized by smaller joint angles, higher flexion velocities, and higher pole force applied during a shorter poling phase"

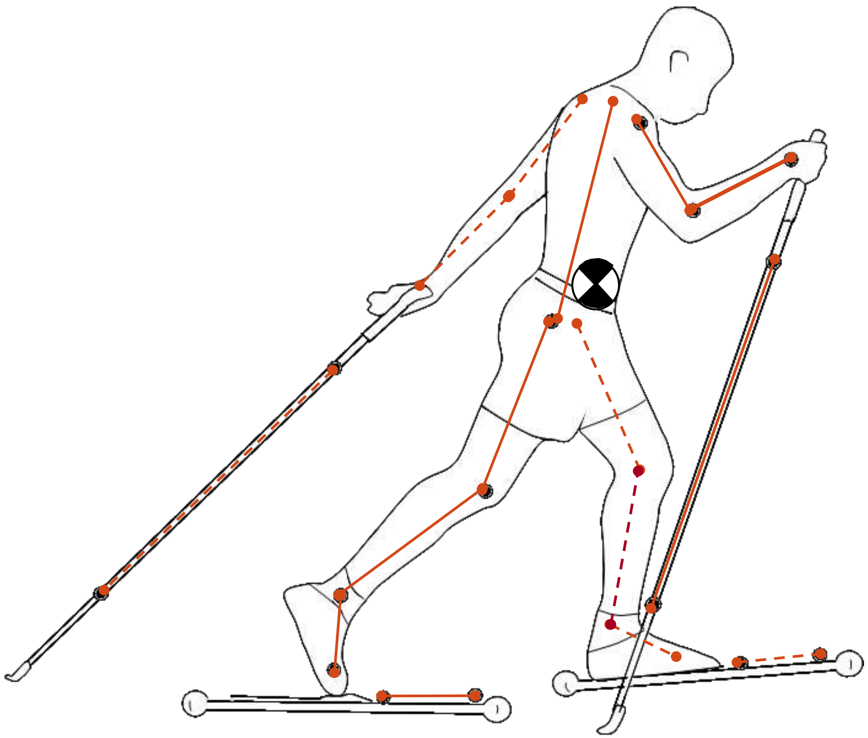
Cross-country skiing biomechanics
..from many segments to body COM

How to describe body motion
in more..general and simplified way??

Body COM

COM is the point at which the entire weight of a body may be considered as concentrated.

The resultant of all forces acting on the body can be considered as applied on COM.



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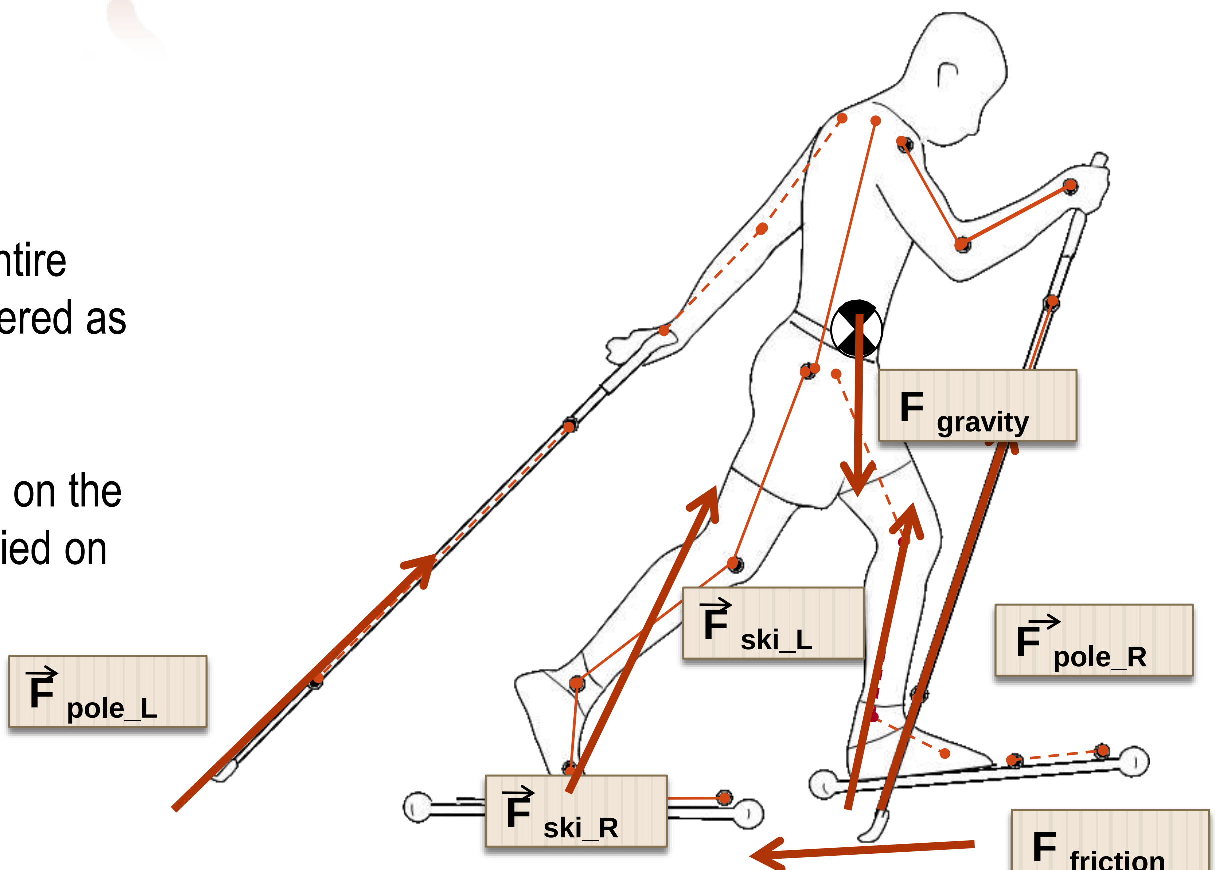

Cross-country skiing biomechanics ..from many segments to body COM

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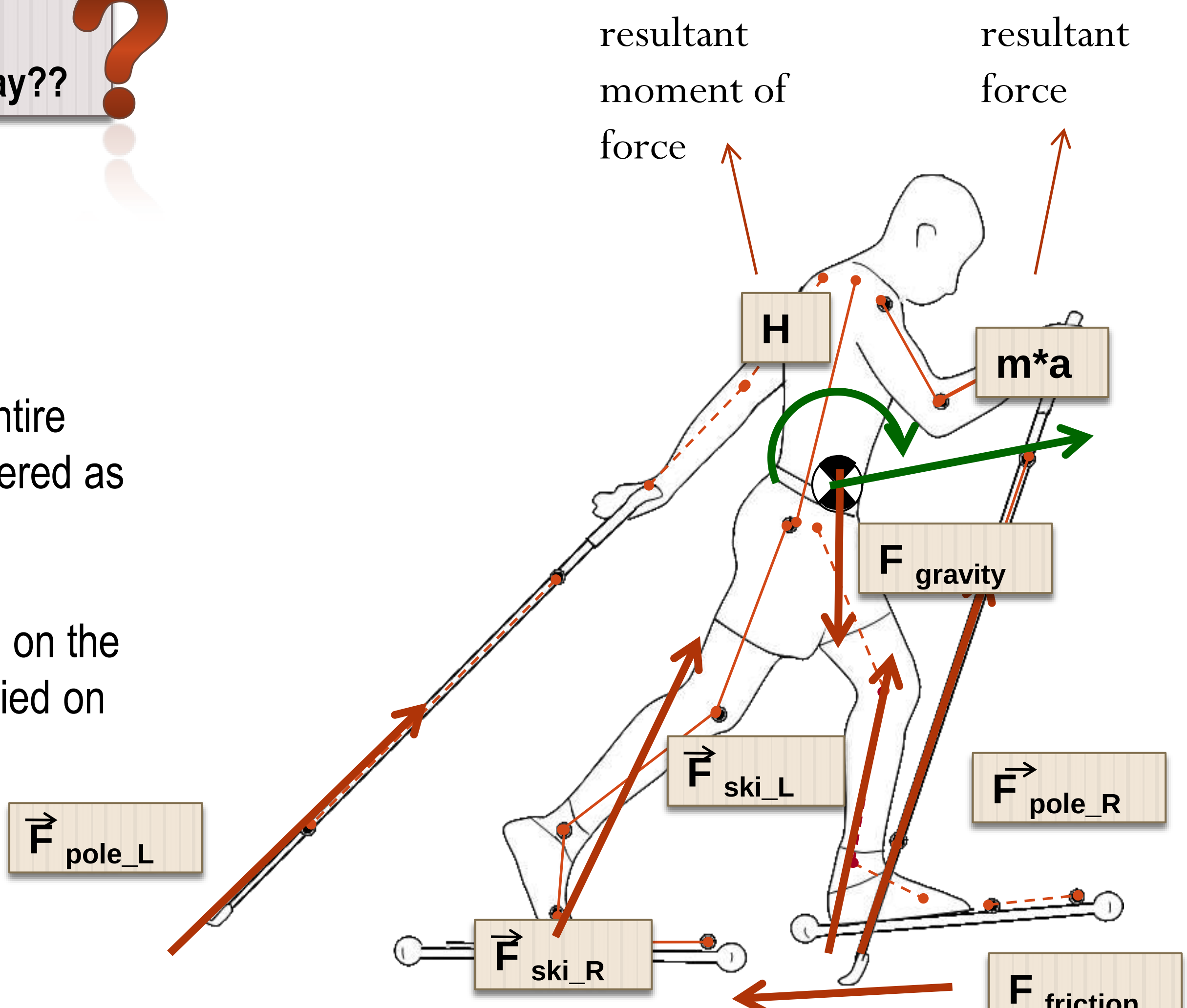
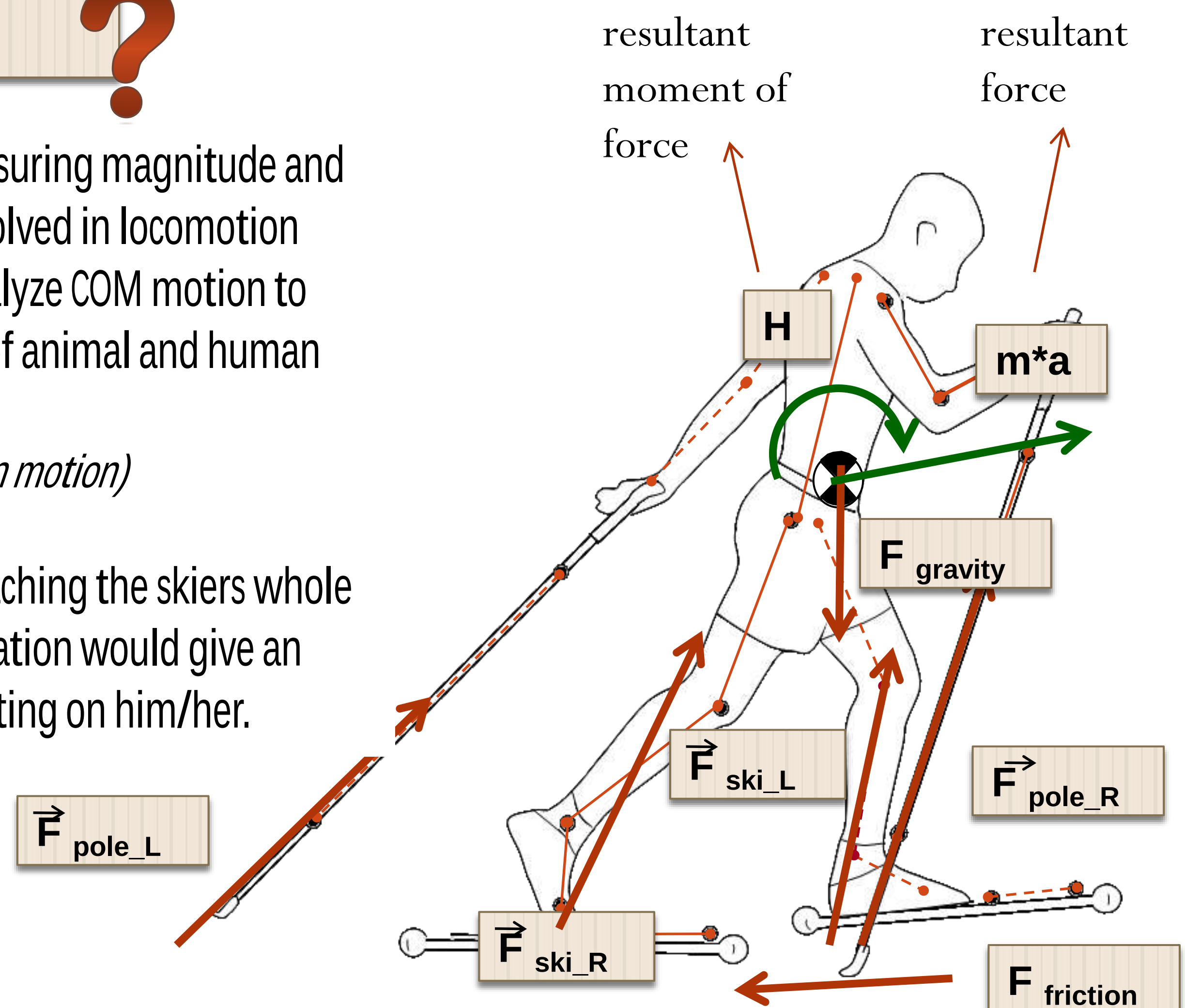


Cross-country skiing biomechanics ..from many segments to body COM

Reasons to look at COM

The impossibility of directly measuring magnitude and point of application of forces involved in locomotion inspired many researchers to analyze COM motion to derive some mechanical aspect of animal and human movement
(Zatsiorsky , 2000, Kinetics of human motion)

Looking at COM, would mean catching the skiers whole motion and analyzing its acceleration would give an idea of the effect of the forces acting on him/her.



body COM..a simplified view, not a simplified measurement

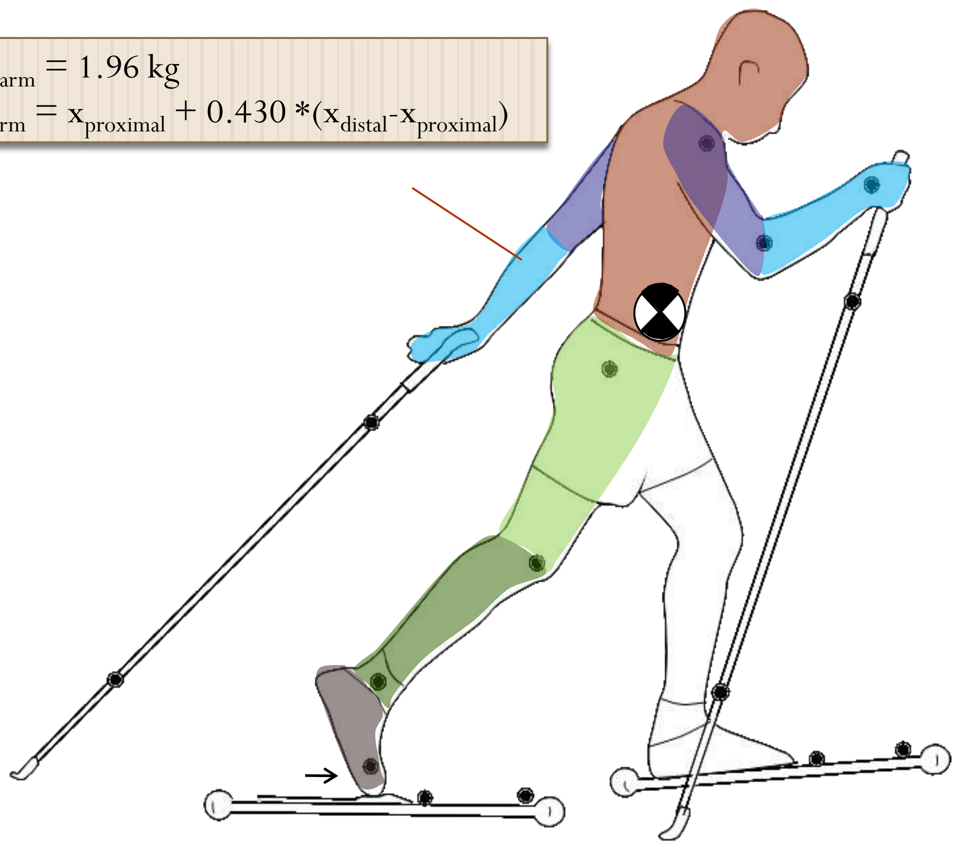
How to calculate body COM

$$x_{COM} = \frac{\sum_i x_i m_i}{M}$$

$$y_{COM} = \frac{\sum_i y_i m_i}{M}$$

Mass and center of mass position of each body segments are ***approximated*** and taken for anthropometric table
(*Dempster 1955, de Leva (1996)*)

$m_{forearm} = 1.96$ kg
$x_{forearm} = x_{proximal} + 0.430 * (x_{distal} - x_{proximal})$



Measurements setup

Roller skiing on the treadmill:

- no variability of environmental condition
- fixed and precise speed and slope
- many consecutives cycles

Treadmill belt: 2.5 m wide 3.5m long

Poles: various length

Rollers skis: Nord CL, ski skett

Rolling friction coefficient: μ = 0.024

comparable with other treadmills *(Kwamme, 2005, Hoffman, 1995)*
and lower than typical on snow skiing μ = 0.01 - 0.10
(Colbeck 1994)

Most published data on cross country skiing originated from roller skis studies on treadmill
(Kwamme, 2005, Hoffman, 1990, Millet 1998, Mahood 2001, Holmberg 2005)

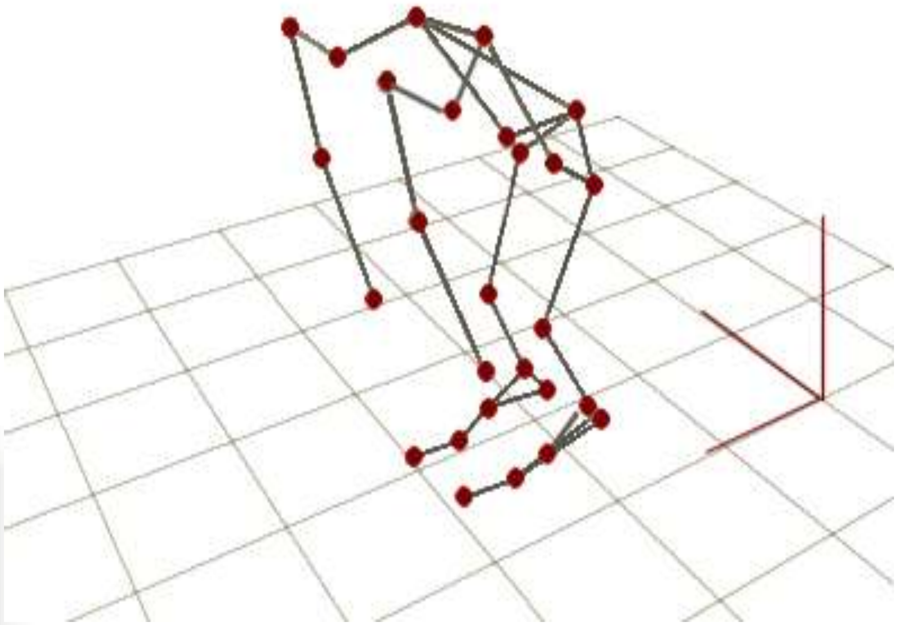
Double Poling - DP **Double Poling with kick - DK** **Diagonal Stride - DS**

Laboratory measurement - Motion Capture

6 infrared cameras (ProReflex, Qualisys)
placed on both side acquiring 3D motion at 100Hz

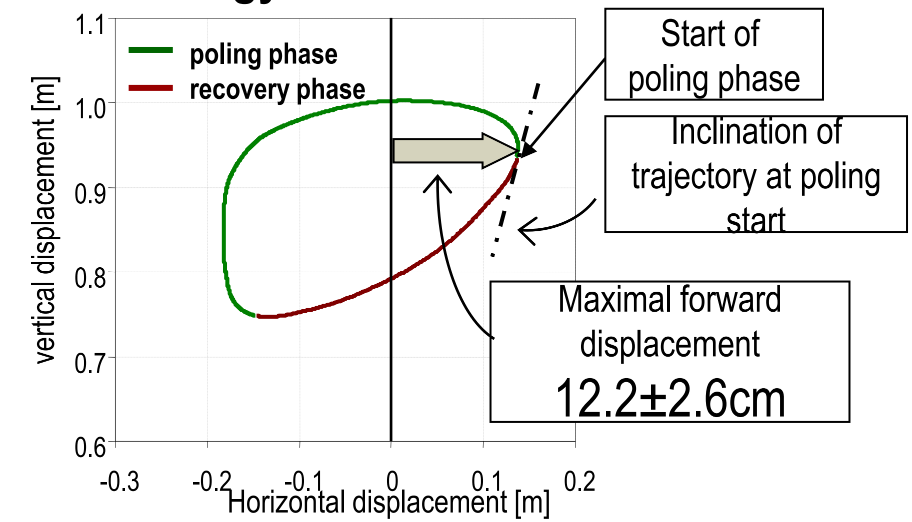
2 markers on every pole and ski
18 markers on body landmarks

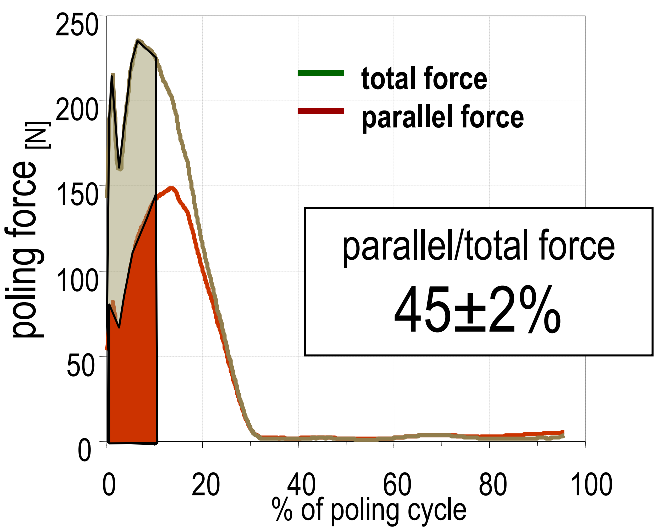
12 body segments + **pole and ski motion**



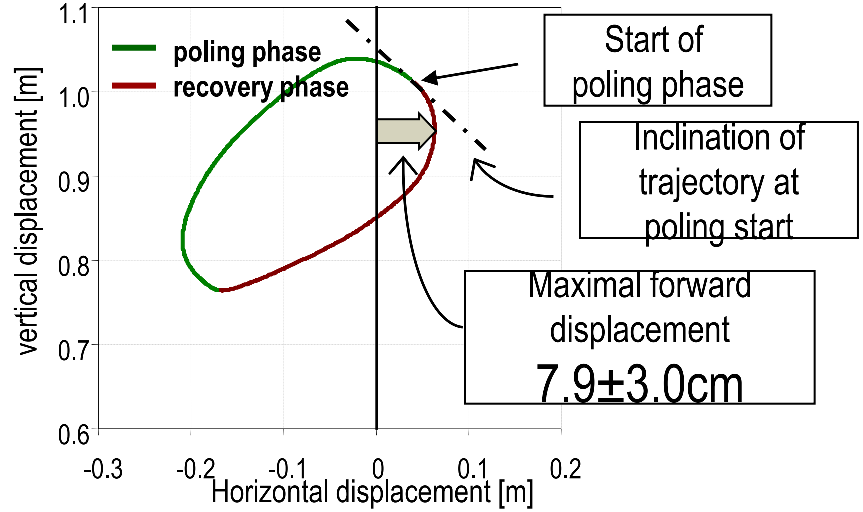
Skiers body COM motion displacement

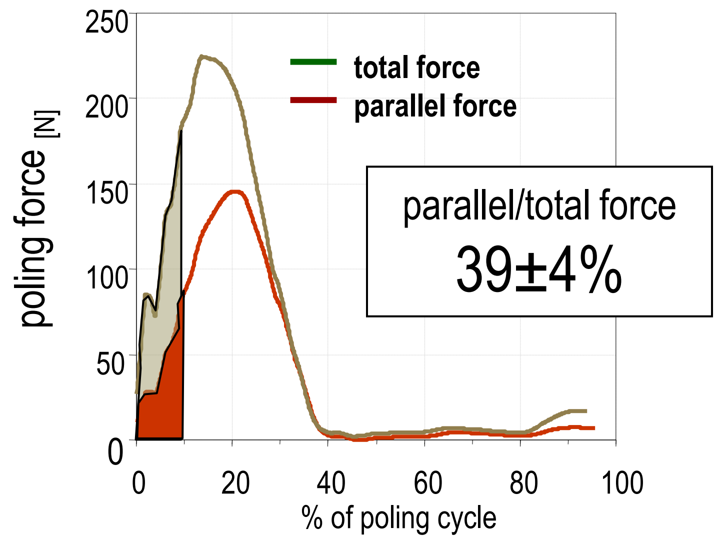
Strategy A- 3 skiers





Strategy B – 7 skiers





Centre of mass motion influences pole force application on double poling roller skiing, Book of Abstract 12th Annual Congress of the ECSS Jyvaskyla, (Finland), Pellegrini e al 2007

Skiers body COM motion displacement

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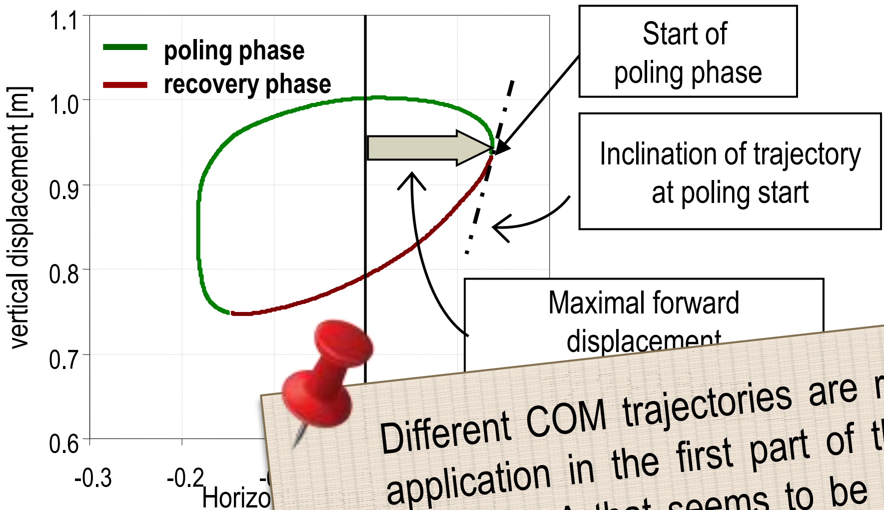
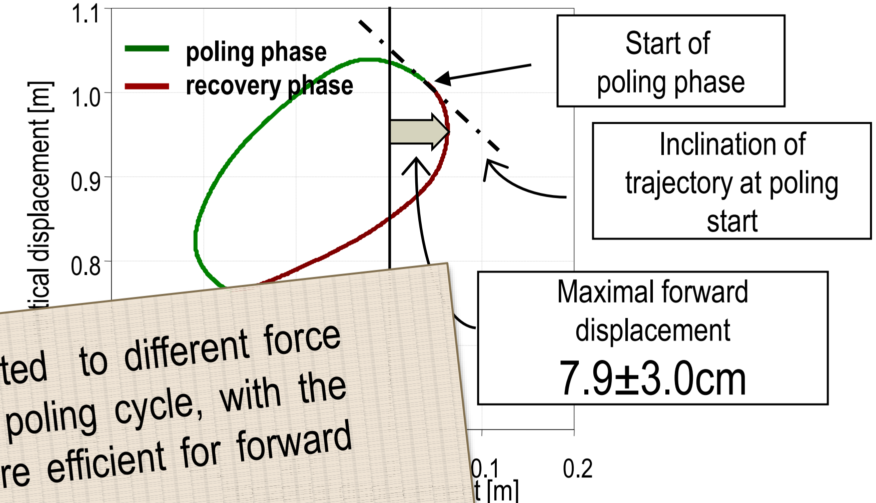
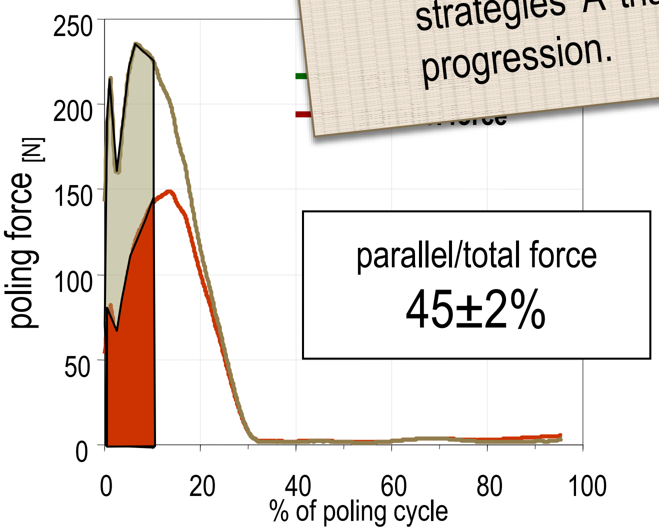
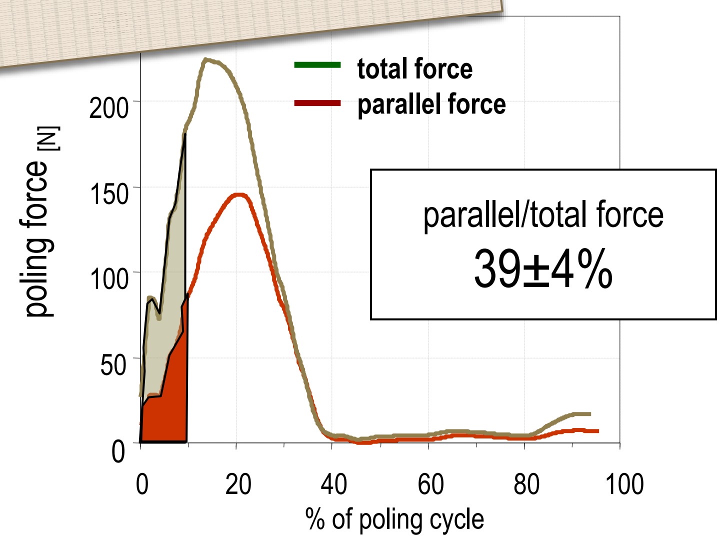


Strategy B – 7 skiers



Different COM trajectories are related to different force application in the first part of the poling cycle, with the strategies A that seems to be more efficient for forward progression.





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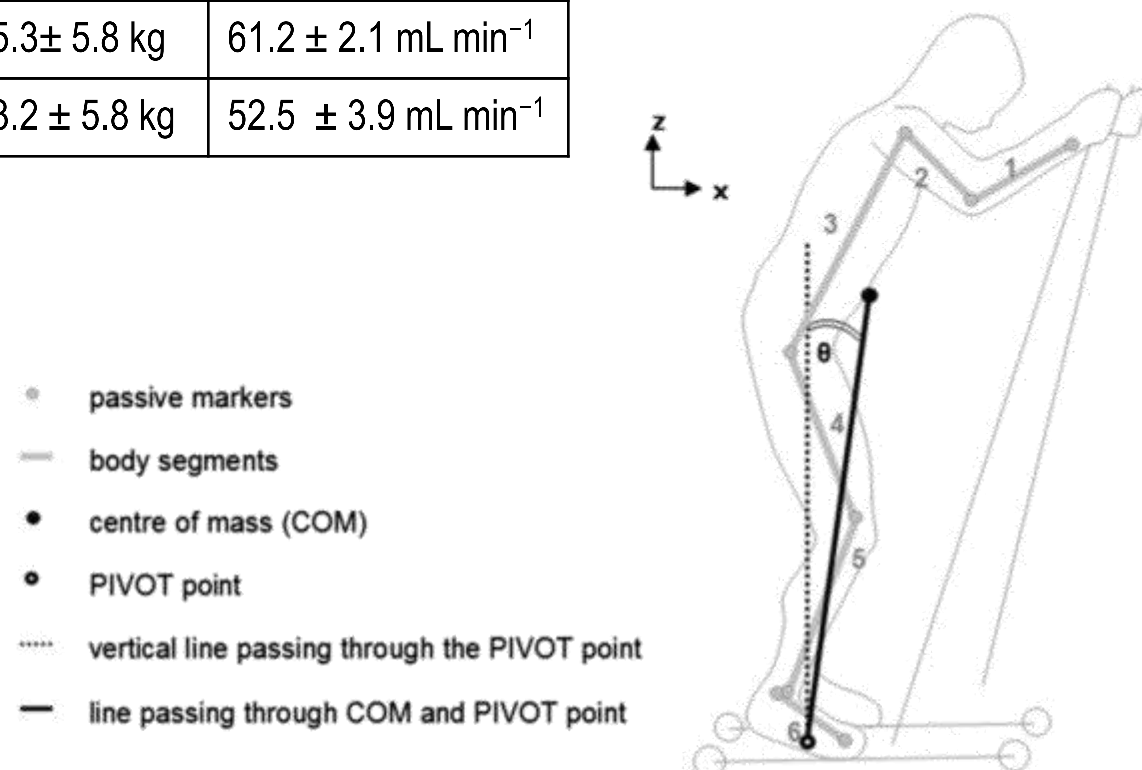
Eur J Appl Physiol (2015) 115:969–979
DOI 10.1007/s00421-014-3078-4

ORIGINAL ARTICLE

Energetics and biomechanics of double poling in regional and high-level cross-country skiers

Chiara Zoppirolli · Barbara Pellegrini ·
Lorenzo Bortolan · Federico Schena

subjects	stature	body mass	VO_2max
8 high level	1.81 ± 0.04 m	75.3± 5.8 kg	61.2 ± 2.1 mL min^{-1}
8 regional level	1.79 ± 0.05 m	73.2 ± 5.8 kg	52.5 ± 3.9 mL min^{-1}



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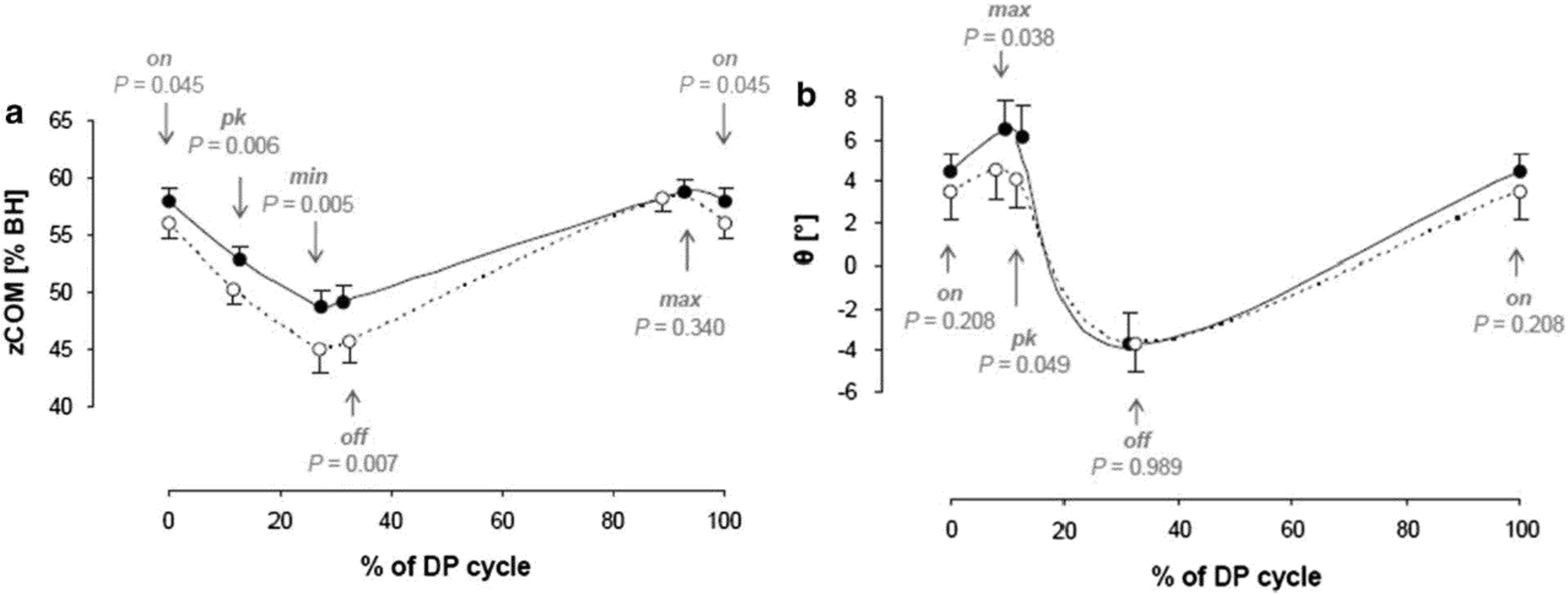
“the **COM vertical displacement range** was significantly lower in high level group than in regional level group “

Body forward inclination at pole plant was significantly higher for high level skiers



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Skiing economy

A forward multiple regression revealed that skiing economy was related to (AdjR (2) = 0.734; $P < 0.001$))
- the maximum value of θ (θ max)
- the minimum value of COM vertical displacement

Moreover, θ max positively related to poling force integrals and cycle duration ($P < 0.05$).

CONCLUSIONS:

A pronounced body inclination during the early poling phase and a reduced COM vertical displacement range concur in explaining the differences in skiing economy

A mechanically advantageous motion of COM during DP improves poling effectiveness, reduces cycle frequency and the mechanical work sustained

The energy associated to COM motion

$$E_{COM} = Mgh_{COM} + \frac{1}{2}Mv_{COM}^2$$

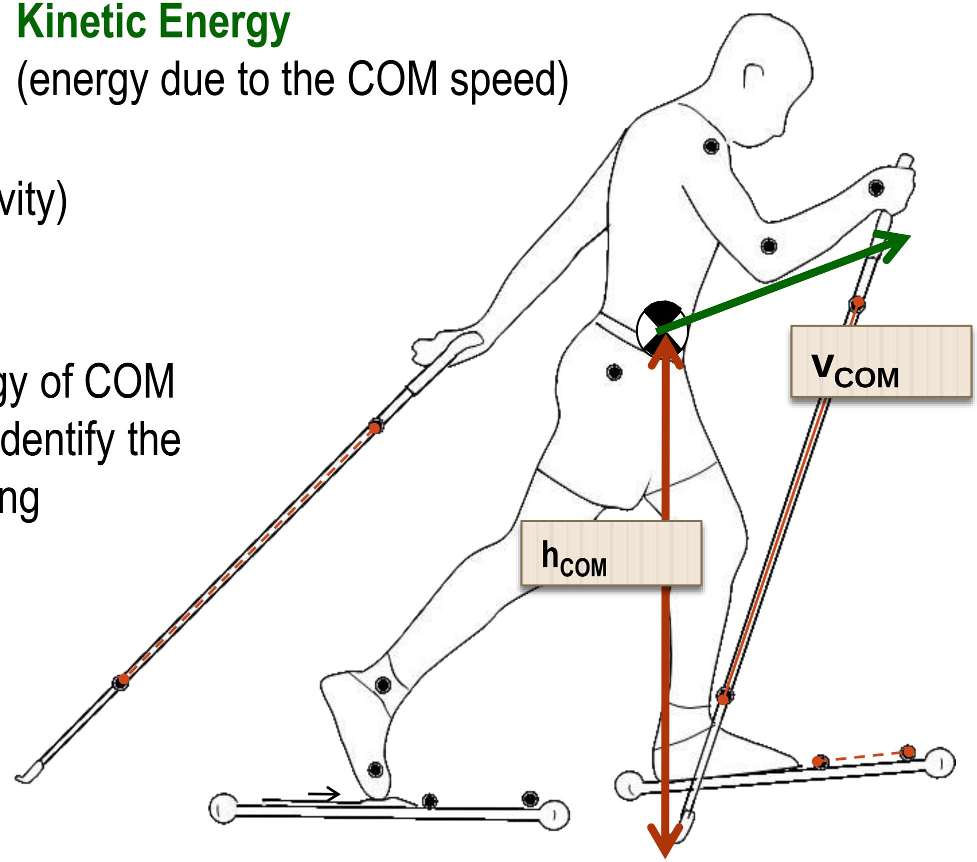
PE

KE

Kinetic Energy
(energy due to the COM speed)

Potential energy
(energy due to the COM position against gravity)

The analysis of the fluctuation of the energy of COM in cross country skiing can be adopted to identify the underling mechanism of cross country skiing techniques

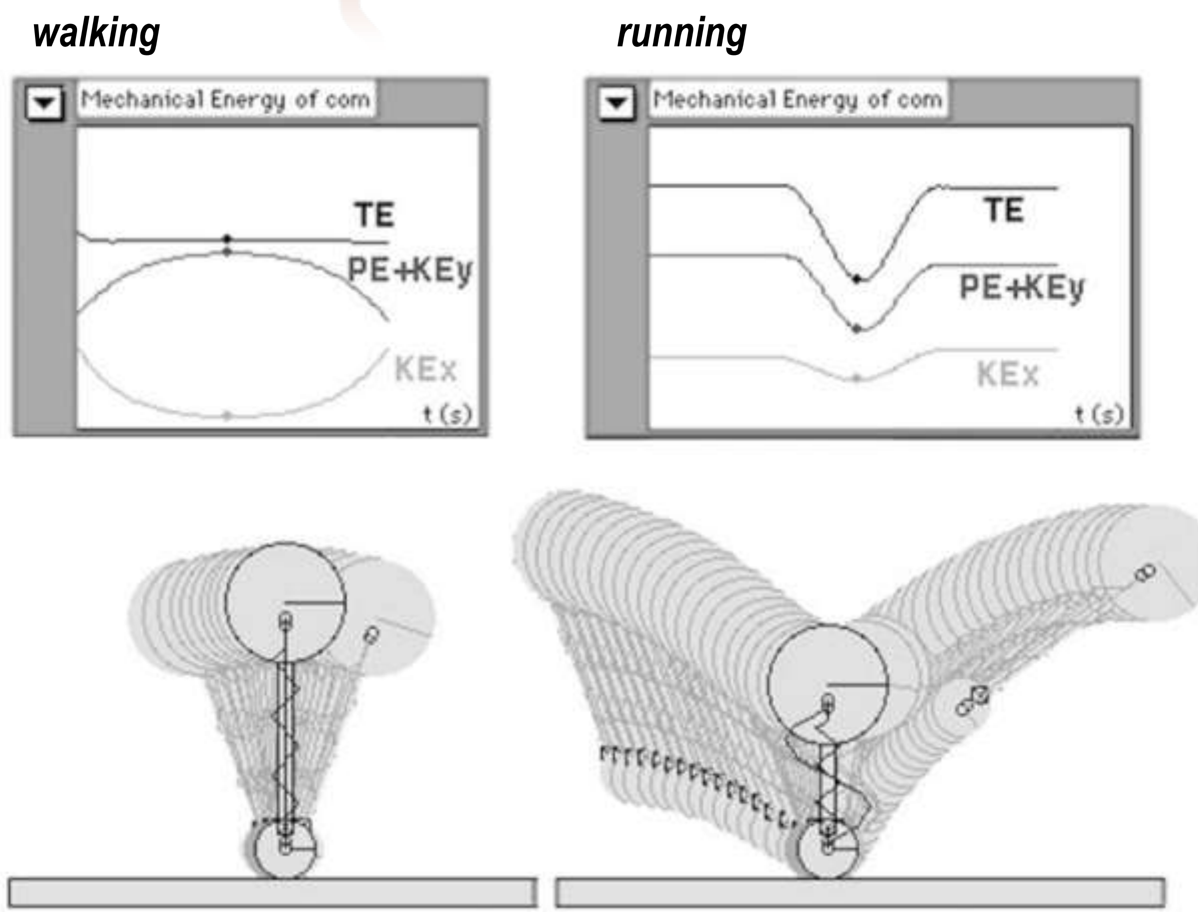


....from body COM to Energy...

Why to look at COM Energy

mechanical energy fluctuations can help in identifying the fundamental mechanisms that underlie terrestrial gait and to distinguish between different gait modes

It has been widely used in human and animal locomotion



Modified from Saibene and Minetti 2003

....from Energy to Mechanical Work...

The work energy principle !

$$E_{COM} = Mgh_{COM} + \frac{1}{2} Mv^{2}_{COM}$$

PE

KE

Sum of positive and negative changes of E

W_{ext_com}
Works for moving COM

Sum of positive changes of E

W_{ext_com}
Works for moving COM

classical definition of mechanical work:
Work = Force X speed

when knlowldege of force not always possible

calculation of mechanical work based on the changes of body energy

$$W_{walking} = \cancel{W_{environment} +} W_{COM} + W_{int}$$

$$W_{running} = W_{environment} + W_{COM} + W_{int}$$

$$W_{cycling} = W_{environment} + W_{COM} + \cancel{W_{int}}$$

$$W_{skiing} = W_{environment} + W_{COM} + W_{int}$$

Cavagna, G. A. J.Physiol (1969)

di Prampero, P. E. (1986)

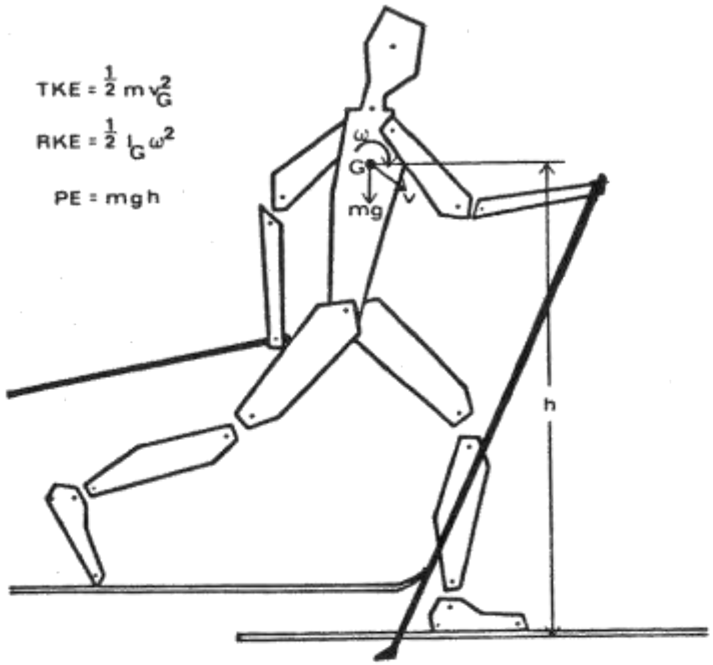
Willems, P. A., Cavagna, G. A., & Heglund, N. C. (1995)

Francescato MP, Girardis M, di Prampero PE. (1995)

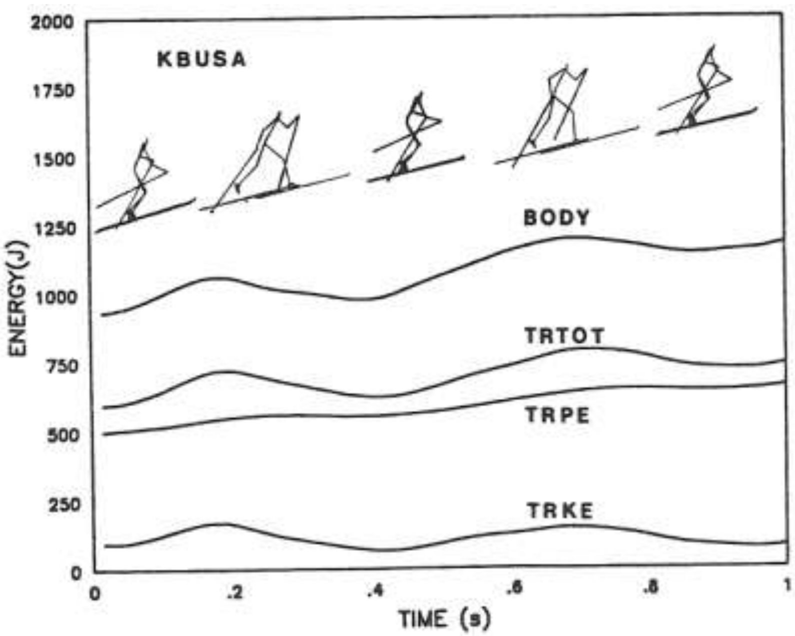
INTERNATIONAL JOURNAL OF SPORT BIOMECHANICS, 1989, 5, 169-184

Mechanical Power Output and Estimated Metabolic Rates of Nordic Skiers During Olympic Competition

Robert Norman, Sylvia Ounpuu, Margo Fraser, and Ronald Mitchell



“We have chosed ....to include not only phases of increasing energy level in the total work output estimate but to add the absolute value of the reductions in the energy level”



This may produce an overestimated of the mechanical power ouput. Ignoring the negative work will porduce and underestimate. The reality is somewhere in between

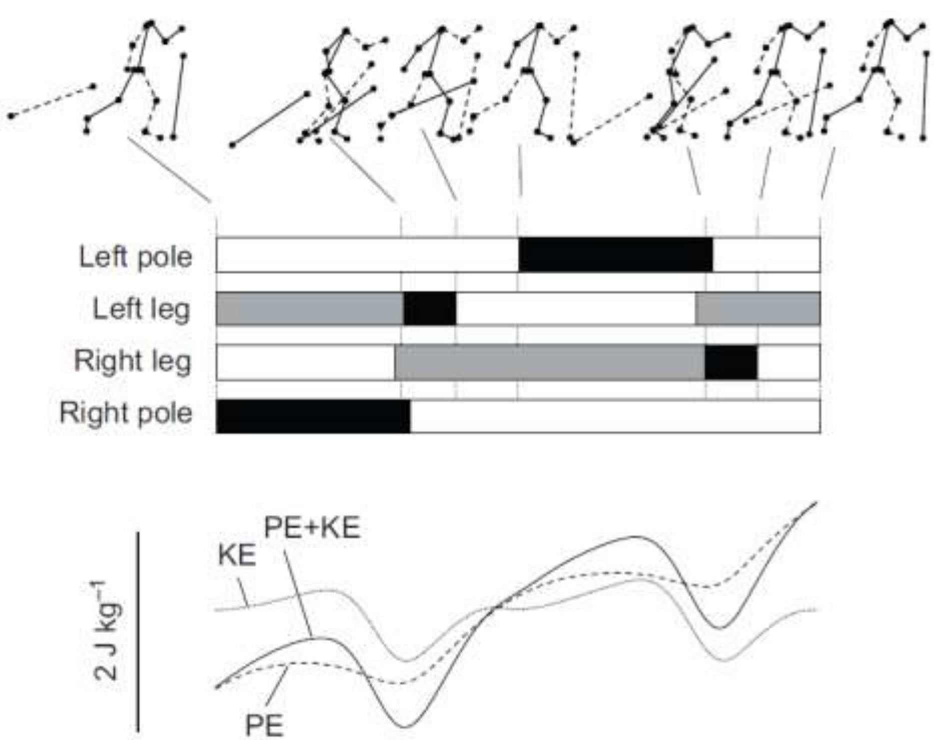
 | The Journal of Experimental Biology (2014) 217, 3910-3918 doi:10.1242/jeb.106740

RESEARCH ARTICLE

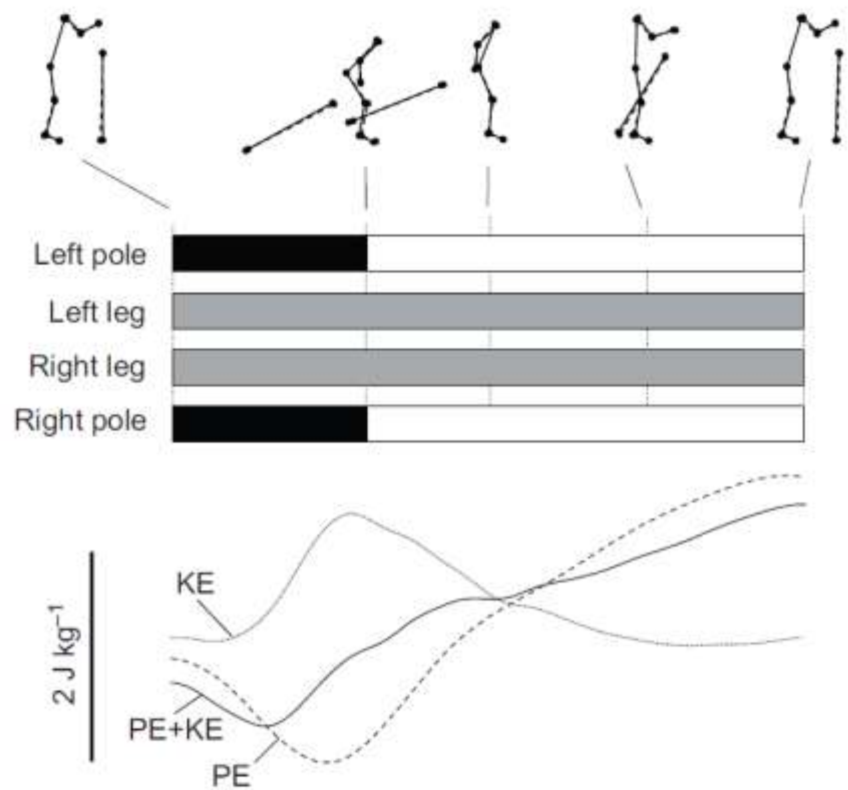
Gait models and mechanical energy in three cross-country skiing techniques

Barbara Pellegrini[1,2,*], Chiara Zoppirolli[1,2], Lorenzo Bortolan[1,2], Paola Zamparo[2] and Federico Schena[1,2]

Diagonal stride



Double poling



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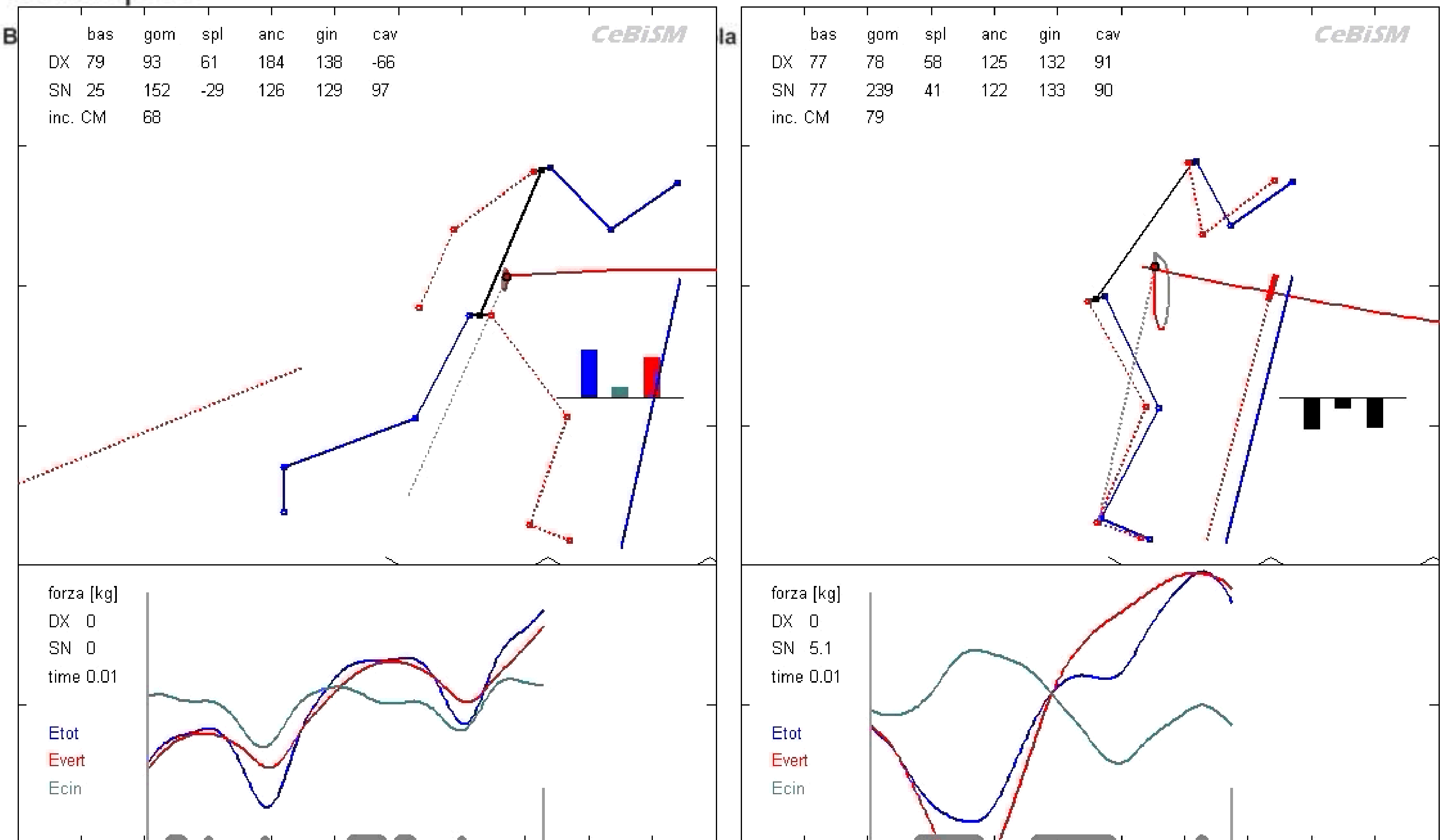

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RESEARCH ARTICLE

..from Energy to mechanical Work...

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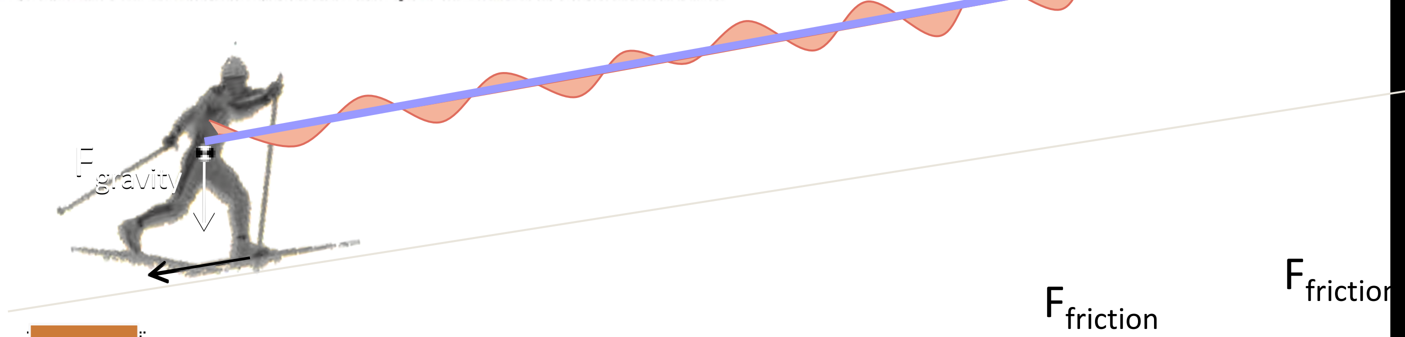

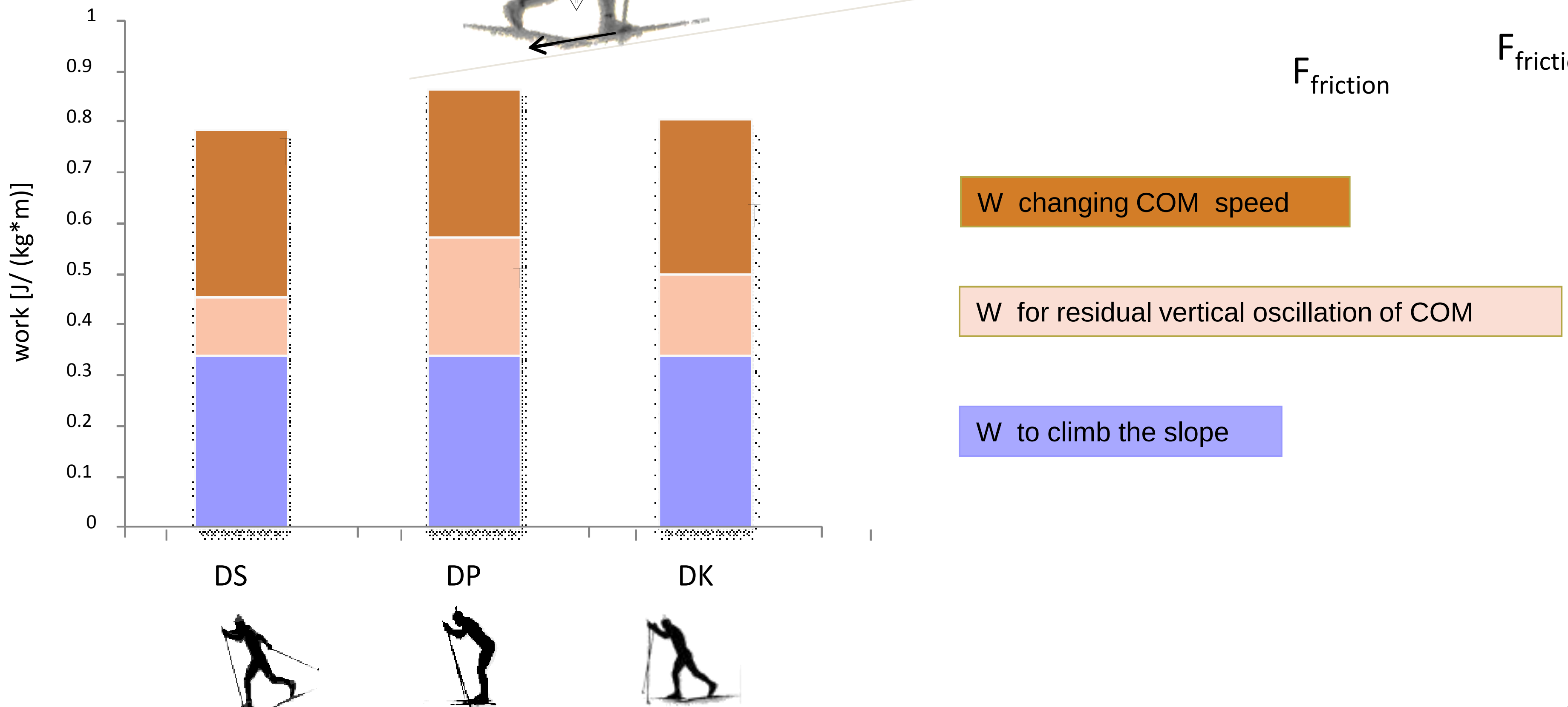

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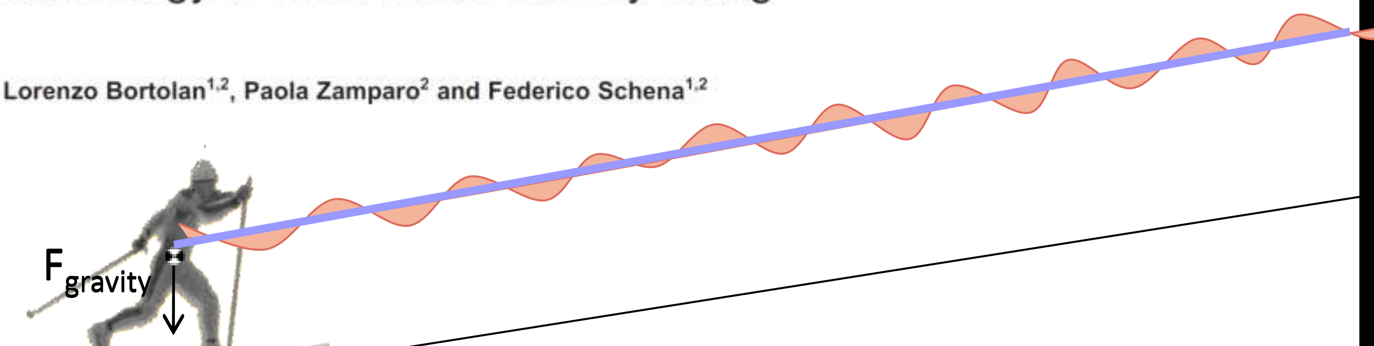

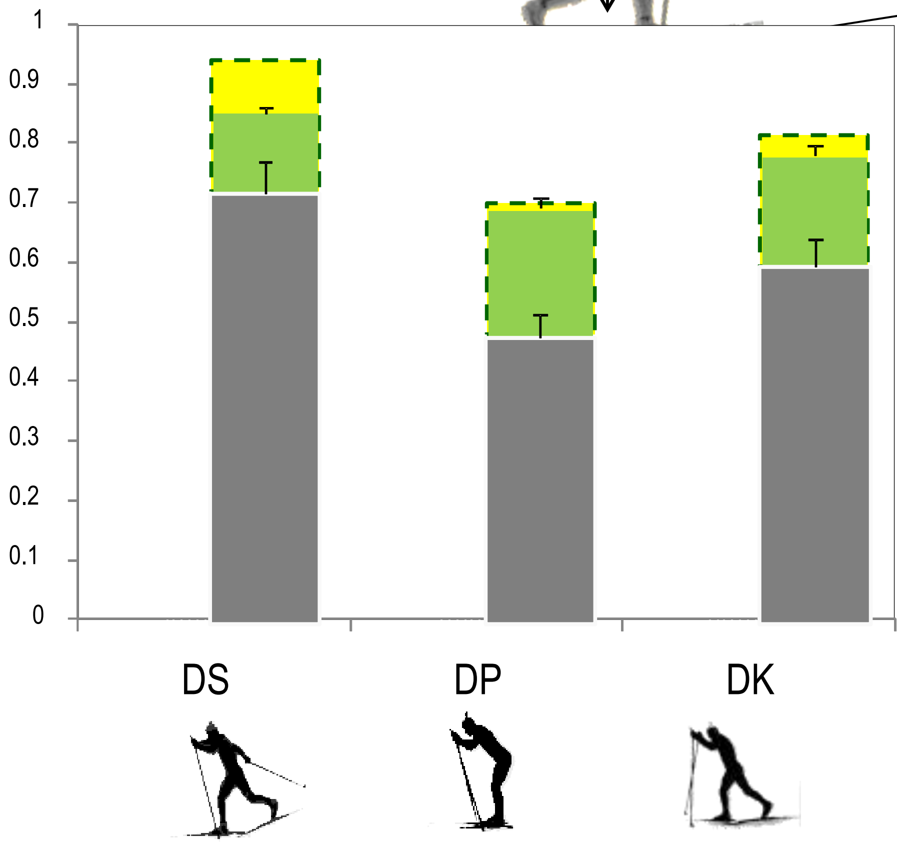

W for friction - estimation

W for friction – exact calculation

distance covered by rolling on skis/total distance travelled
DP = 100% DS = 41% DK = 83%

the frictional work calculated by considering the instantaneous values of speed and load on the skis, is 68% for DS and and 86%, for DP of that estimated

In conclusion

By analyzing the movement of the center of mass we can have an idea of the effects of the forces applied on a skier and their subsequent translation into movement and velocity

Determination of body COM requires:
- Measurements of all forces

or
- Measurements of movements of all segments

Fluctuations of body COM can give insight in cross country skiing as gait modes

Calculation of mechanical work from energy fluctuations could add information in determining

Calculation of mechanical works requires to drawn assumption on unknown mechanisms, the results are estimation, may differ from true values

Cross country skiing analyzed from center of mass point of view

research center - Rovereto (TN)
CeRiSM
sport mountain health

Pellegrini Barbara
Zoppirolli Chiara
Bortolan Lorenzo
Schena Federico

Thank you very much