BIOMECHANICAL CHARACTERISTICS RELATED TO POLING PROPULSIVE EFFECTIVENESS IN CROSS-COUNTRY V2 SKATING TECHNIQUE

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The purpose of this study was to investigate whether specific kinetic and kinematic characteristics distinguish the propulsive effectiveness of upper body in V2 cross-country skating technique. Female and male skiers (n=25) performed V2 on a treadmill using roller skis at a 6% incline, while kinetic parameters of plantar pressure and ski pole forces, as well as 3d-kinematic data were collected. The ratio between propulsive and overall impulse (effectiveness) of ski poles was 50% for female and 52% for male athletes and highly correlated with ski pole angles. Male skiers showed smaller pole angles at maximum propulsive force than females (P<0.05). Athletes should consider a more effective ski pole planting angle in order to improve propulsive poling action and consequently their performance.

KEYWORDS: kinematics, kinetics, propulsion, efficiency

INTRODUCTION: In cross-country skiing, the propulsion of upper and lower body is conveyed to the snow using skis and poles using specific coordinative patterns that distinguish the different sub-techniques. Drag and propulsive (i.e. in the skiing direction) forces are the main factors determining speed, especially in skating technique where skiers reach higher speeds in comparison to classic technique (Kvamme, Jakobsen, Hetland & Smith, 2005). V2 skating, also called G3 or double dance, is characterized by one symmetrical double pole push for each leg stroke and has become the main sub-technique during competitions due to its high adaptability from flat to moderate inclines. Although Smith, Kvamme and Jakobsen (2009) have stated that in V2 poles mainly contribute to propulsion and that the proportion of the propulsive force in relation to the overall force is an efficiency indicator in cross-country skiing, the relation between poling effectiveness and other biomechanical characteristics are not deeply investigated in this sub-technique. Previous studies showed how a correct pole orientation and timing coincide with higher efficiency of force application in V1 (Stöggl & Holmberg, 2014), diagonal stride (Pellegrini, Bortolan & Schena, 2010) and double poling (Holmberg, Lindinger, Stöggl, Eitzlmair & Müller, 2005). The purpose of the present study was to investigate how high ski poles' propulsive effectiveness is connected to kinetic and kinematic characteristics in V2 skating, with the goal of helping coaches and athletes to develop a more efficient technique.

METHODS: In the study, twenty-five subjects (n=12 female; n=13 male; age 24 ± 4 years; body mass 68.0 ± 10.6 kg; body height 1.76 ± 0.08 m) competing at National and International level (cross-country skiing and biathlon) performed on a treadmill (HP Cosmos, Germany) using the same pair of roller skis. After a warm-up familiarizing with the treadmill, the subjects skied using V2 for 30 seconds at an incline of 6% and at a fast but comfortable speed of 5 m/s for females and 6 m/s for males.
A 24-camera 3d-motion capture system (Vicon, Oxford, UK) was instrumented around the treadmill and kinematics were measured at 200 Hz. A set of 45 reflective markers was positioned on the subjects following the Plug-in-Gait marker set (with two additional markers on the knees, three markers on each pole and roller ski). The kinematic data were analysed using Vicon Nexus 2.5 software (Vicon, Oxford, UK). Kinetic data of plantar pressure insoles were collected at 100 Hz using Pedar insoles (Novel GmbH, Munich, Germany) and ski poles instrumented with a custom-made force measurement system (V. Wank, University of

Tübingen, Germany) with a sampling rate of 1600 Hz. Kinetic and kinematic data were further processed using Matlab R2016a (Mathworks Inc., Natick, MA, USA).
Parameters of upper and lower body kinetics were pole and insole impulse, peak and contact time. The poles' vertical (F_z) and propulsive (F_{prop}) force components were calculated combining the ski poles' 1d force data with the resulting angle between the poles and the treadmill running surface derived from the 3d kinematics. The pole angles of maximum impact force (αF_z) and maximum F_{prop} (αF_{prop}), flexion/extension range of motion (ROM) of ankle, knee and hip and cycle time (CT) and length (CL) were determined from the kinematic data. Poling propulsive effectiveness ($\%SPF_{prop}$) was determined as the ratio between the F_{prop} impulse and the overall impulse.
The collected data of female and male athletes were analysed separately. All analyzed kinetic characteristics are normalized to body weight and presented as means and standard deviations of ten consecutive cycles (figure 1). In order to determine relationships between kinematic and kinetic variables in V2, Pearson correlations were calculated. The statistical analysis was performed using IBM SPSS Statistics for Windows (IBM Corp., Armonk, NY, USA). The criterion for the statistical significance was set at $\alpha<0.05$.

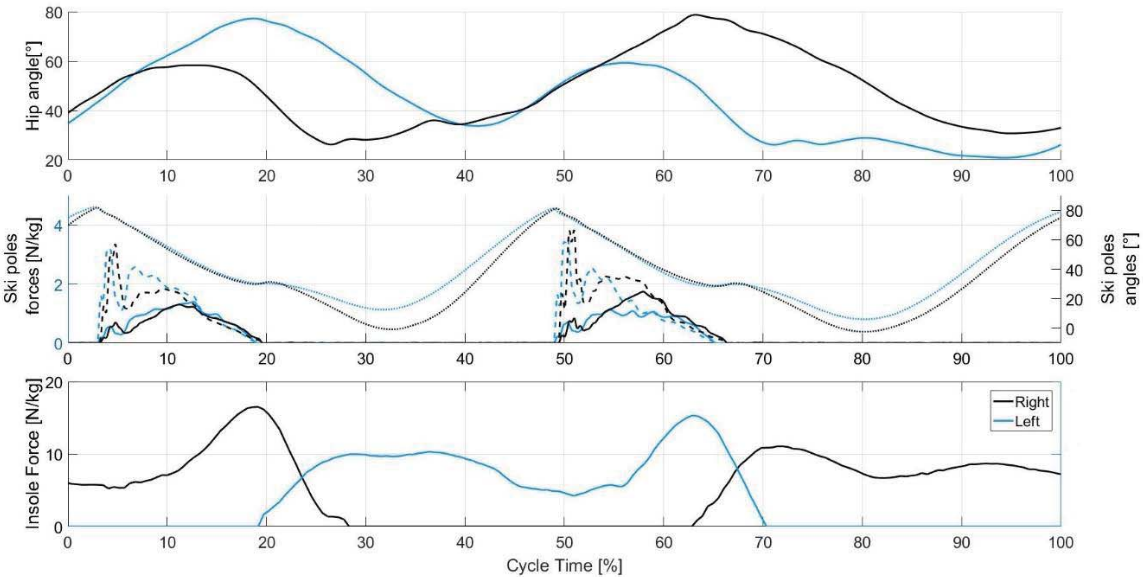

Figure 1: Exemplar (n=1) data of one skating cycle and representative left and right kinematics and kinetics. Top: hip flexion/extension angle. Middle: ski pole angles (dotted line) and pole force components F_z (dashed line) and F_{prop} (solid line). Bottom: insole plantar forces.

RESULTS: The main variables analysed during the study for male and female groups are presented in table 1. Male propulsive effectiveness was 52%, while 50% for females, whereas the ski pole maximum F_{prop} angle was lower for male than female skiers ($p<0.05$).
$\%SPF_{prop}$ was correlated with αF_{prop} (female r=-0.62, male r=-0.82, all $p<0.05$), and with αF_z (r=-0.70, $p<0.05$) in the male group. $\%SPF_{prop}$ also correlated with the propulsive impulse in the female group (r=0.69, $p<0.05$) and with the SP impact peak (r=-0.62, $p<0.05$) and to the ratio between SP contact time and CT (r=-0.56, $p<0.05$) in the male group. SP overall force was correlated with the ratio between the time to reach F_{prop} and the pole contact time (female r=-0.74, male r=-0.75, all $P<0.05$) and, for male skiers, with the hip ROM (r=0.63, $p<0.05$). Both groups showed a correlation between CT and F_{prop} impulse (male r=0.71, female r=0.65, $p<0.05$), foot contact time (male r=0.75, female r=0.79, all $p<0.05$) and pole contact time (male r=0.80, female r=0.90, all $p<0.05$). For the females, the ROM of ankle, knee and hip were correlated with F_{prop} impulse (r=-0.60, r=-0.64, r=-0.62, respectively, all $p<0.05$), with overall impulse (r=-0.63, r=-0.65, r=-0.77, all $p<0.05$), and with F_{prop} peak (r=-0.60, r=-0.74, r=-0.66, all $p<0.05$). Gliding time correlated with the F_{prop} impulse in both genders (female r=0.61, male r=0.55, all $p<0.05$). No correlation was found between the

upper and lower body kinetic variables, except for the overall leg impulse and F_{prop}.peak set at 0.62 ($p<0.05$) for the males.

Table 1
Cycle characteristics, kinematic and kinetic variables in V2

Variable	Female (n=12)	Male (n=13)
Cycle time [s]	1.72 ± 0.12	1.82 ± 0.15
Cycle length [m]	8.62 ± 0.59	10.94 ± 0.91
SP overall impulse [Ns/kg]	0.43 ± 0.05	0.44 ± 0.06
SP impact peak [N/kg]	2.97 ± 0.43	2.63 ± 0.54
SP F_{prop} impulse [Ns/kg]	0.22 ± 0.03	0.23 ± 0.03
SP F_{prop} peak [N/kg]	1.33 ± 0.17	1.64 ± 0.15
%SPF_{prop} [%]	52 ± 4	50 ± 3
SP contact time [s]	0.27 ± 0.02	0.26 ± 0.02
SP F_{prop} peak time/contact time [%]	57 ± 5	59 ± 6
Poling contact time/CT [%]	31 ± 1	29 ± 1
αF_{prop} [°]	45 ± 3	42 ± 3
αF_z [°]	70 ± 2	68 ± 6
Leg overall impulse [Ns/kg]	6.67 ± 0.91	7.07 ± 1.12
Leg push-off force peak [N/kg]	14.31 ± 1.28	14.87 ± 1.81
Leg push-off impulse [Ns/kg]	3.10 ± 0.42	3.18 ± 0.48
Gliding time [s]	0.88 ± 0.14	0.98 ± 0.16
Foot contact time [s]	1.01 ± 0.08	1.05 ± 0.09
Push-off time [s]	0.42 ± 0.05	0.42 ± 0.03
ROM ankle [°]	42 ± 6	42 ± 4
ROM knee [°]	59 ± 6	58 ± 5
ROM hip [°]	63 ± 5	64 ± 5

DISCUSSION: The goal of our study was to examine how specific kinetic and kinematic characteristics interact and influence the propulsive effectiveness of poling in V2 skating technique. The results revealed that, performing at an incline of 6%, the propulsion constitutes 50% of the overall impulse for female at 5 m/s and 52% for male skiers at 6 m/s. The values were smaller than the 67-70% reported by Smith et al. (2009) with the same technique, but justifiable by different treadmill inclines. Irrespective of gender, the highest correlations between poling propulsive effectiveness and kinematics were found with the ski pole impact and propulsive force peak angles. In fact, the magnitude of force components results from the product between the overall poling force and the angle between ski poles and forward direction. Consequently, the propulsive force can be increased decreasing the angle between pole and forward direction (Smith et al., 2009; Pellegrini et al., 2010). At this stage of data analysis, it is unclear if and how different strategies of pole planting influence propulsion. Further analysis of the upper body kinematics like trunk and arm motions could reveal how different strategies of pole planting affect propulsion as Holmberg et al. (2005) demonstrated happening in double poling.
In terms of time-related variables, the time to reach the pole force peak and the foot and pole contact time could be analysed. Holmberg et al. (2005) showed the importance of a short time to reach the pole force peak for improving the propulsive effectiveness in double poling. However, in our study we found negative correlation between the time to reach the maximum propulsive force and the overall peak force but not with the propulsive effectiveness. Moreover, male athletes with lower effectiveness showed a bigger ratio between pole contact time and cycle time. This might be explained by the fact that, as suggested by Pellegrini et al. (2010) for diagonal stride, an increase of the pole contact time causes an increase of the poling force. In addition, Stöggl and Holmberg (2014) reported that the reduction of foot and pole contact time leads to an increase of the propulsive effectiveness and of the cycle rate in V1. We suggested that this strategy could be common also in V2, since the propulsive impulse and the contact time of foot and pole correlated with the cycle characteristics in our study.

The ranges of motion of lower body joints were related to the ski poles overall, propulsive impulse and propulsive force for the female; however, in both groups almost no correlation was found with the leg kinetics. Differently from V1 where steady propulsive forces are guaranteed by upper and lower body propulsion (Stöggl & Holmberg, 2014), V2 is characterized by an important gliding phase; therefore, the increase of the propulsive effectiveness leads to a gliding increase, as demonstrated by its correlation with the propulsive impulse in the study. However, at this point of our analysis the effective overall propulsion is not entirely divided into the relevant components of the upper and lower body impulse and needs further analysis considering also the different inclines and speeds. A key aspect of V2 sub-technique may lay in the centre of mass acceleration and the coordination of pole and foot propulsive forces.

CONCLUSION: In the present study, we investigated poling propulsive force effectiveness in relation to biomechanical characteristics in V2 skating technique. As expected, our results prove that ski pole angle is the main factor influencing propulsive effectiveness. Therefore, athletes should focus on planting the ski poles at a smaller angle with the ground incline in order to increase the proportion of propulsive force and the connected effectiveness. Lastly, further analysis focused especially on arms' kinematics could reveal the most efficient strategy of ski poles planting.

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