Ground reaction from poles and ski in cross-country skiing and 3-D kinematic analysis
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INTRODUCTION

Double poling technique in cross-country skiing is receiving always more attention by coaches due to the fact that it represents a dominant technical strategy for large sections of sprint races. From the kinematic point of view, double poling is a fairly easy, symmetric movement, which mainly involves the upper part of the body and relies on upper limbs action for propulsion. Nevertheless, slight differences in the position of trunk, shoulders, arms and poles were reported to cause considerable differences in the resulting propulsion effects (Smit et al., 1996).

The correlation of specific features of double poling kinematics (joint angles, linear and angular velocities and acceleration of body segments) with the resulting whole body acceleration represents a particularly enlightening method for the technical optimisation of the technique. However, alternative valuable indications are expected by applying inverse dynamic modelling for the estimation of the intersegmental loads at the upper limbs level, as a function of the specific movement strategy. This work was based on multifactorial movement data acquisition during double poling and reports the quantification of the inter-segmental dynamic moments at elbow and shoulder level estimated by means of an inverse dynamic approach. Results demonstrate that the local evaluation of forces and moments at specific joints on the upper body can be related to the overall propulsion effect produced by the athlete.

METHODS

Data collection was performed in January 2004 on the cross-country track in Valdidentro, Italy. Two athletes were enrolled in the study and were asked to perform a sprint race simulation. Athletes were fitted with equipment for kinetic movement analysis consisting of (Figure 1):
- 2 hydrodynamic piezoelectric pressure sensors for ground reaction measurement
- 2 strain-gauges based sensors for the measurements of dynamic inputs form poles
Sensors were connected to a portable, unencumbering data logger unit, which was attached to athletes’ waist.
Movement kinematics was measured by means of a couple of digital camcorders (SONY) working at 50 Hz. They were located on the track in correspondence of a flat terrain section.

Figure 1. Experimental equipment for dynamic data acquisition from poles and feet.
where both athletes used double poling technique. Dedicated software for video analysis, with free panning, tilting and zooming TV cameras (Baroni et al., 1998) was used to cover a wide working volume. Calibration was performed by means DLT method (Aziz and Karara, 1971). The maximal error was lower than 2% for coordinates and about 5% for differential variables. The biomechanical model of the skier consisted of 23 landmarks; 4 of these points were used for poles and skis identification.

An inverse dynamic approach was applied for the estimation of the movement dynamics from movement kinematics. The method is based on Newton’s equations and allows estimating the inter-segmental loads associated with movement production by imposing the equilibrium of forces and moments at each joint. The basic hypothesis consists of modelling the human body in a simplified set of rigid segments forming a kinematic chain (Figure 3).

The analysis initiated at the wrists level, where the dynamic measurement of the axial force acting on the pole was available, and proceeded through the elbows and the shoulders. Moments were calculated with respect to a local joint mounted reference frame, which allowed us to express the moments with anatomical correspondence (Figure 4).
RESULTS

Figure 5 depicts the intersegmental loads calculated at elbows and shoulders for the two athletes. When the dynamic patterns at the shoulder levels are considered, flexing and adductive moments turn out to be preponderant with respect to intra-rotation action. On the contrary, at the elbow level, the intra-rotation actions are dominant with respect to flexion-extension moment. Figures well explain how the dynamic actions produced at shoulder level are transferred passively through the elbows (intra-rotation action) while combining with those actions (extension action) produced actively by the arm extensors (triceps muscles). Slight asymmetries and delays are shown by both athletes at both joints. Athlete 2 exhibits higher peak values with respect to athlete 1 as well as a much stronger action produced by the right arm with respect to the left one. Higher moments produced more efficient propulsion effects for this subject, who was able to increase by more than 30% his whole body speed with respect to athlete 1.

Figure 5. Intersegmental loads at shoulders (upper panels) and elbows (lower panels) for athlete 1 (left panels) and athlete 2 (right panels). Red and blue colors refer to left and right limb, respectively.
SUMMARY AND DISCUSSION

A method for multifactorial movement analysis and biomechanical modelling for the inter-segmental load estimations at upper limbs during double poling in cross country skiing was described. The technique is based on the synchronised acquisition of kinematic data by means of 3-D motion capture and video digitalisation and dynamic measurements from poles. Inverse dynamics modelling was used to estimate the loads at the elbows and shoulders produced by the specific kinematic strategy described in 3-D. Loads estimation started from the dynamic measurement obtained from the sensors mounted on the poles. Data from 2 athletes engaged in a sprint race simulation were acquired. Although only few experimental data were considered in this analysis, results demonstrated a correlation between the size of the estimated dynamic actions and the propulsive effects of the poling. This suggests that inverse dynamics might be a valuable modelling tool associated with low encumbering experimental apparatus, in order to optimise the kinematics of the double poling technique as a function of the corresponding dynamic actions produced by specific angular strategies involving shoulder, elbows and poles.

REFERENCES

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