GROUND REACTION FORCES AT PUSH-OFF AND TIME PERFORMANCE OF THE START IN THE DOWNHILL OF ELITE SKIERS
R. POZZO1,2, A. CANCLINI1, C.COTELLI1, L.MARTINELLI1, G. DeMONTE1
1) LAP–Federazione Italiana Sport Invernali 2)Ufficio Studi e Ricerca Metodologica CONI

INTRODUCTION
In downhill the results obtained by elite athletes are very close to each other, so that a few hundreds of second can make the difference towards winning a race. Therefore, every little improvement of the total time can make the final difference. In past studies (Mueller 1991) the effects of different type of the leg movement before starting and the force exerted on the ground were analysed in an experimental situation. There are not so many relevant studies under normal conditions on the snow and with top level athletes.

The purpose of this study was to evaluate the relationship between the characteristics of force production at the push-off and the time and velocity performance in the 50 m subsequent to the start.

METHODS
Two special force plates were placed at the left and right side of the starting gate to allow the acquisition of the force exerted on the ground by the poles (fig.1). The force plate used a one-direction strain-gauge sensor (Leane-Parma). Force data were collected with 500 Hz sampling frequency. Force-time curves were analysed for following parameters: maximal force (Fmax), average force (Fav), force impulse (IM), total push-off time (Ttot) and time from begin of push-off to switch-on the starting gate (Tgate). The ground slope was 43%.

For the time acquisition a telemetry system was used (0,001 s resolution Microgate-Trento) which allows separate lap time recording. Time cells were located at 2,5m, 6,5m, 10,5m, 14,5m, 23,5m, 32,5m, 41,5m and 50,5 m in front of the starting gate. The system was triggered by the starting gate. Elapsed partial and progressive time as well as average velocity with respect to marker’s distance were calculated. Furthermore video sequence were recorded for later 2-D analysis. Seven skiers (84 ± 3 body mass and 178 ± 2 cm body height) of the Italian national team participated in this investigation. All the subjects performed 5-8 starts with maximal effort.

Fig. 1 Experimental setup
RESULTS
Time performance
The time performance of travel distance indicate a different relationship to the starting phase (fig.2). Subject G.K. shows the lowest results at 6,5m and at 50,5m marker, while R.P. maintains the longest values in both the laps. At 50,5m marker, Subject V.P. improves the time in greater extend compared to P.W.
On the other hand there is a good correlation between the time at the 6,5m marker and the time at the 50,5m one (r=0,84). So the better the skier is at the beginning, the better he is at the 50m. It should be remembered, that the time values give indirect information on the average velocity obtained in the laps and not on the instantaneous values (s. peak velocity in the work presented by Pozzo in this book).

Dynamics
In fig. 3 are reported the time history curve of force produced on both left and right poles for two representative skiers (V.P. and G.K.). The most evident differences are the duration of the total push-off time and the slope of force development.
Time parameters of push-off are not always consistent within the subjects, V.P. and C.L. show a different relationship between Ttot and Tgate with respect to the number of trials (fig. 4). The mean duration is 687 ± 70 ms for Ttot and 452 ± 52 ms for Tgate. Fig 5 shows dynamic parameters during different trials. Fmax indicates different pattern concerning left and right symmetry (P.W. and V.P. versus R.P. and G.K.) and also variability with respect to the number of trials.

Less variation was found for Fav and IM, whereby there
are still significant differences between subjects. Mean values are $F_{\text{max}}$-R $281 \pm 56$ N, $F_{\text{max}}$-L $262 \pm 50$, $F_{\text{avg}}$-R $179 \pm 73$ N, $F_{\text{avg}}$-L $177 \pm 31$ N, IM-R $147 \pm 26$ Ns and IM-L $120 \pm 18$ Ns.

**Correlation analysis**

There are some correlations of the push-off time with the dynamics: $F_{\text{max}}$-R ($r=-0.46$ with $T_{\text{tot}}$, $r=-0.49$ with $T_{\text{gate}}$), $F_{\text{avg}}$-R ($r=-0.76$ with $T_{\text{tot}}$, $r=-0.74$ with $T_{\text{gate}}$), $F_{\text{avg}}$-L ($r=-0.58$ with $T_{\text{tot}}$, $r=-0.57$ with $T_{\text{gate}}$) and force impulse IM-L ($r=0.61$ with both $T_{\text{gate}}$ and $T_{\text{tot}}$). Subjects with high $F_{\text{max}}$ and especially with high $F_{\text{avg}}$ have low $T_{\text{tot}}$ and $T_{\text{gate}}$. The time performance of travel distance indicate a small correlation with push-off parameters. It was found a negative correlation between $F_{\text{max}}$-R and the time at the 6.5 m marker ($r=-0.47$) and a positive one between IM-L and the time at the 2.5m marker ($r=0.46$). Therefore, it seems that high values of maximal force and low values of the force impulse could induce a shorter time in the early part of the travel distance. It should be noted, that the force and relative impulse are the normal (vertical) component of the resultant force respectively impulse.

**DISCUSSION**

Except for a small negative relationship with the maximal force, and a positive one with the impulse, there is no significant correlation between time performance and the dynamic parameters. Indeed, the performance time is triggered by opening the gate with the feet and
this movement could be performed relatively independently from the poles pushing. The vertical force also could be more related to the performance with increasing ski slope. Furthermore, the skating movements and the materials determine the total time performance at 50.5m. Best time performance at 2.5 m and also at 6.5m from start was achieved by G.K. who shows the longest pushing time (Ttot) and also high values of Tgate. On the contrary, V.P. reached the the lowest Ttot and Tgate values but the highest Fmax and Fav values. The correlations of Ttot with Fmax and Fav indicate that a longer push-off time could be of benefit if the Tgate is maintained long as well.

The results of Fmax and relative impulse are by far greater than those reported by Mueller, (1991) this could be related to the different ski slope and to the subject’s strength capacity.

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Institut für Sportwissenschaft, Innsbruck