MUSCLE COORDINATION IN CROSS-COUNTRY SKIING: THE EFFECT OF INCLINE ON THE V2-SKATE TECHNIQUE

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This study examined differences in upper (UB) and lower-body (LB) muscle activation of twelve elite Nordic skiers using the V2-skate at two inclines via electromyography (EMG). Subjects roller-skied on a treadmill for two 2-minute bouts, one at moderate grade - high speed and one at steep grade - low speed to keep heart rate equal between bouts. EMG was recorded (10-second interval), normalized to maximal isometric voluntary contraction, and analyzed for cycle time, peak and average activation, and within-cycle times for activation onset, offset, and peak activation of each muscle. UB tended to remain active for a longer proportion of the cycle at steeper grades while the opposite was true of LB. UB may play an increased role in the V2-skate at steeper grades independent of intensity, although no significant difference in LB or UB response to grade was found ($p < 0.05$).

KEY WORDS: Nordic ski technique, muscle activation chain.

INTRODUCTION: Holmberg and colleagues have described a "muscle activation chain" of upper-body (UB) muscles in classical style double-pole technique, in which the abdominals, latissimus dorsi, and triceps brachii are activated in rapid succession at pole-plant (Holmberg, Lindinger, Stöggl, Eitzlmair, & Müller, 2005). The UB muscles used with the V2-skate technique, used during freestyle races, mimic those used double-poling while the lower-body (LB) muscles such as the gastrocnemius and rectus femoris reach peak activation during the push-off (Suchý & Kračmar, 2008).
As grade increases with constant speed, skiers using the V2-technique match the increased required mechanical power by increasing both aerobic power (VO_2) and mechanical efficiency (Sandbakk, Ettema, & Holmberg, 2012). Skiers achieve better efficiency at steep grades by decreasing cycle time (CT) and increasing the relative poling phase (Sandbakk et al., 2012), but adjustments in muscle coordination that increase efficiency at steeper grades have not yet been analyzed. Past studies have examined the effect of grade on physiological markers (Millet, Hoffman, Candau, & Clifford, 1998; Pellegrini, Bortolan, & Schena, 2011a; Sandbakk et al., 2012), and several studies have investigated muscle coordination or activation of skiing on flat terrain (Cignetti, Schena, Zanone, & Rouard, 2009; Holmberg et al., 2005; Nilsson, Tinmark, Halvorsen, & Arndt, 2012; Nilsson, Tveit, & Eikrehagen, 2004; Suchỳ & Kračmar, 2008), but none to our knowledge have examined how muscle activation patterns change with grade.
Techniques such as the V1-skate that rely more heavily on the legs for propulsion are more efficient to use at steeper inclines (Kvamme, Jakobsen, Hetland, & Smith, 2005). This may be because the legs have lower levels of lactate onset, higher capillary density, and are better than the arms at consuming lactate as an aerobic fuel source (Calbet, 2005; Holmberg, 2015; Popov & Vinogradova, 2012). It is logical then that skiers will increase reliance on the legs for propulsion when using the V2-skate on steeper grades. We hypothesize that at steeper grades skiers will achieve greater increases in LB muscle activation than UB muscle activation, shorter cycle lengths, and longer periods of muscle activation relative to each cycle (implying longer poling phase).

METHODS: Twelve former or current NCAA cross-country skiers age 18-28 volunteered for the study (n = 7 males, height: 179.4 $\pm$ 6.39 cm, weight: 74.1 $\pm$ 5.73 kg, VO_2-max: 73.9 $\pm$ 6.05 mL/kg·min; n = 5 female, height: 166.4 $\pm$ 7.61 cm, weight: 60.4 $\pm$ 5.13 kg, VO2-max: 62.63 $\pm$ 2.52 mL/kg·min). All subjects were informed of the nature of the study before giving their written consent to participate. The research methods were approved by the University's Institutional Review Board prior to execution (Project #HS15-695).

On testing day each skier first completed a short 5-10 minute warmup on the treadmill (FitNex #1812; Houston, TX). Surface electromyography (EMG) electrodes were applied to the skin over five muscles of interest: rectus femoris (RF), rectus abdominis (RA), gastrocnemius (G), latissimus dorsi (L), and triceps brachii (T). Prior to application the skin at each location was prepped by shaving, abrading with 150-grit sand paper, and wiping clean with an alcohol pad. Each electrode was tested with an ohmmeter to ensure impedance below 20 kΩ.

Once electrodes were in place, each subject performed a maximal isometric voluntary contraction (MVIC) for each muscle then roller-skied at two different grade-speed combinations (males: 10%, 3.35 $m \cdot s^{-1}$ and 6%, 4.25 $m \cdot s^{-1}$; females: 8%, 3.13 $m \cdot s^{-1}$ and 4%, 4.47 $m \cdot s^{-1}$) for two minutes each with two minutes easy skiing between. Subjects were cross-matched to which grade-speed combination was tested first. Grade-speed combinations were developed to elicit a similar VO_2 from each bout; heart rate (HR) was recorded at the end of each bout to ensure this aspect in the experiment. EMG data were collected for 10 seconds during the last quarter of each bout with a wireless EMG-analysis system (BTS Bioengineering FreeEMG 300; Milan, Italy) at a frequency of 1000 Hz, and the program EMG Analyzer was used to filter (10-450 Hz band pass), rectify, and integrate (over 50 ms) each signal.

MATLAB programs were written to normalize each signal over each muscle MVIC, compute mean CT, mean peak (Muscle_PV) and average (Muscle_AV) activation values, and onset time (Muscle_OnT), offset time (Muscle_OffT), and peak activation time (Muscle_PT) as percentages of CT. CT was defined as the average time between one RA_OnT and the next; OnT and OffT occurred when the EMG signal passed three standard deviations above and below mean baseline amplitude, respectively. Data were exported to Microsoft Excel and IBM SPSS Statistics 23 was used to analyze differences in CT, Muscle_OnT, Muscle_OffT, Muscle_PT, Muscle_PV, and Muscle_AV for each muscle at steep and moderate grades. A paired samples t-test was used to determine any significant differences in these variables between grades. A univariate repeated-measures ANOVA was used to determine if muscles responded differently to a change in grade and a repeated-measures 2 x 5 (grade x muscle) multifactor ANOVA identified any significant effects of muscle and grade on the above variables and tested for a significant interaction between muscle and grade.

RESULTS AND DISCUSSION: The EMG signal for a representative subject at moderate and steep grades (shown in Figure 1) describes the muscle activation chain for V2-skate skiing. While a repeated-measures multifactor ANOVA for muscle and grade found no significant differences between PV and AV of all muscles (independent of grade) and no significant interaction between muscle and grade, significant differences were found between muscles for PT, OnT, and OffT ($p < .05$). A Bonferroni post-hoc test revealed the significant differences in these variables between specific muscles (Figure 1). Our results are consistent with past studies describing the UB muscle activation chain of double-poling (Holmberg et al., 2005) and full activation chain of V2-skating (Suchỳ & Kračmar, 2008) in which RA, L, and T activate in rapid succession followed by the leg push and activation of RF and G.

Our hypothesis that activation of LB muscles would increase with grade was not supported as neither RF nor G showed significant differences in activation between grades (Table 1). A repeated measures ANOVA found no significant differences between any muscles in how those muscles' activation variables changed with grade (ΔPV, ΔAV, ΔPT, ΔOnT, ΔOffT) although UB muscles did nonsignificantly tend to remain activated for a larger proportion of the cycle (+ Δ(OffT-OnT)) on steeper grades while LB muscles tended to decrease in this regard (- Δ(OffT-OnT)) (Table 1). Additionally, a paired samples t-test found significant differences in T_OffT_{steep} and T_OffT_{mod} as well as L_OffT_{steep} and $L\_OffT_{moderate}$ ($p < .05$) (Table 1). These results imply that at steeper inclines the poling phase occurs for a longer portion of each cycle and the leg-push phase for a shorter duration. Although statistically nonsignificant, this difference supports the findings of Sandbakk et al. (2012), who showed an increase in efficiency at steeper grades using the V2-technique due in part to increased poling phase duration. Muscular endurance in the UB may therefore play a greater role in climbing with the V2 technique than in the LB. However we cannot definitively make this conclusion as no subsequent force analysis was performed in this study.

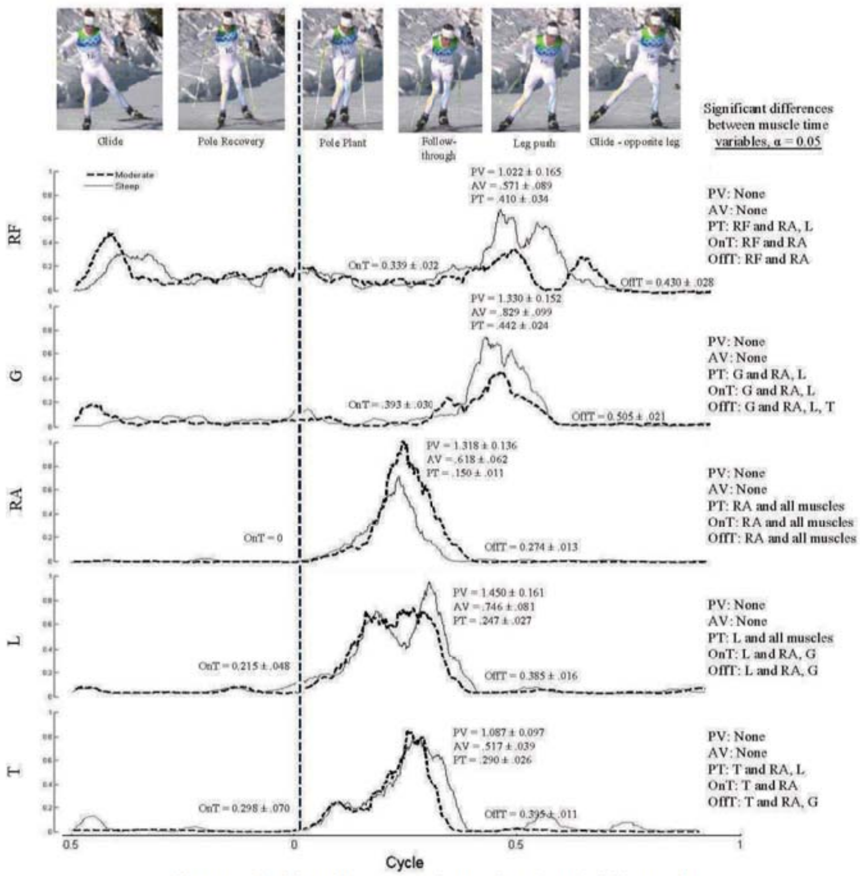

Figure 1. Muscle activation of a single V2-cycle

Table 1. Changes from the moderate grade to the steep grade (e.g. $\Delta PV = PV_{steep} - PV_{mod}$)

Muscle	RF	G	RA	L	T
ΔPV (% of MVIC)	+ 6.40 ± 32.1	+ 14.52 ± 41.1	- 10.63 ± 18.5 [b]	+ 8.02 ± 14.5 [b]	+ 8.16 ± 19.7
ΔAV (% of MVIC)	+ 0.81 ± 24.9	+ 5.30 ± 23.6	- 3.97 ± 12.1	- 0.72 ± 12.2	+ 5.37 ± 9.18 [b]
ΔOnT (% of total cycle time)	+ 4.81 ± 19.2	+ 8.14 ± 22.8	0 (by definition)	- 2.94 ± 21.2	+ 7.73 ± 35.5
ΔOffT (% of total cycle time)	- 1.59 ± 13.5	- 1.89 ± 14.1	+ 4.54 ± 7.66 [b]	+ 7.03 ± 6.56 [a]	+ 8.04 ± 9.76 [a]
Δ(OffT-OnT) (% of total cycle time)	- 6.40 ± 24.9	- 10.04 ± 31.6	+ 4.54 ± 7.66 [b]	+ 9.97 ± 22.8	+ 0.31 ± 35.4
ΔPT (% of total cycle time)	- 0.30 ± 10.5	- 0.84 ± 15.0	+ 2.36 ± 5.31	+ 9.07 ± 15.5 [b]	+ 9.23 ± 18.3

Significant changes ($p < 0.05$) denoted with [a] while changes with ($0.1 > p > 0.05$) are denoted with [b]

CT did not differ significantly between grades ($p > 0.50$); CT was nearly identical between grades and even increased at the steeper grade for some subjects. This contradicts findings of past studies showing decreased CT at steeper grades (Millet et al., 1998; Pellegrini et al., 2011; Sandbakk et al., 2012), but these studies did not hold intensity constant while increasing grade. In our study intensity was held constant between the two grades: A paired samples t-test found no significant difference in HR between steep and moderate bouts ($p > 0.20$).

The current study would have benefitted from video and force analyses and an improved method to identify CT and poling phase. A statistical limitation also existed: many variables changed nonsignificantly at the $\alpha = 0.05$ level and $p < 0.10$ for these changes; thus Type 2 error likely occurred. Recruiting more subjects would decrease the possibility of Type 2 error.

It is possible that separating mechanical efficiency from intensity may have a greater effect on technique and muscle activation than was previously thought. In previous studies researchers that held grade constant while increasing speed found that techniques such as the V1-skate (which utilizes the legs more than V2) are more efficient at steep inclines (Kvamme et al., 2005). It may be that using the legs is simply more efficient at higher intensities but not necessarily at steeper grades. This would align with findings that demonstrate a superior aerobic capacity of the legs (Calbet, 2005) and our findings that muscle activation of selected LB muscles does not increase in V2-skating at steeper inclines when intensity is held constant.

CONCLUSION: We cannot support the hypothesis that muscle activation and coordination significantly change with grade. However our results suggest that there may be a tendency in elite skiers' V2-skate technique that time of LB activation decreases and time of UB activation increases at steeper grades when intensity is held constant. These results suggest that skiers may benefit from additional training of UB endurance, which has been noted as an area for improvement even in elite skiers (Holmberg, 2015). Past studies suggest that the legs become physiologically important with increased metabolic demand. This implies that skiers should take into account both the grade of a hill and their exertion when determining which technique or sub-technique is most efficient. At steep grades and low VO_2, for example during pack skiing, skiing with increased UB activation may be most efficient, while skiing at steep grade and high VO_2, for example at the end of a race, increased LB activation may be advantageous.

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