SKI SKATING TECHNIQUE CHOICE: MECHANICAL AND PHYSIOLOGICAL FACTORS AFFECTING PERFORMANCE

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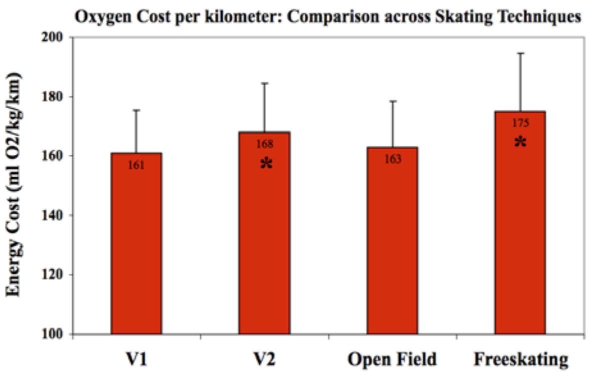
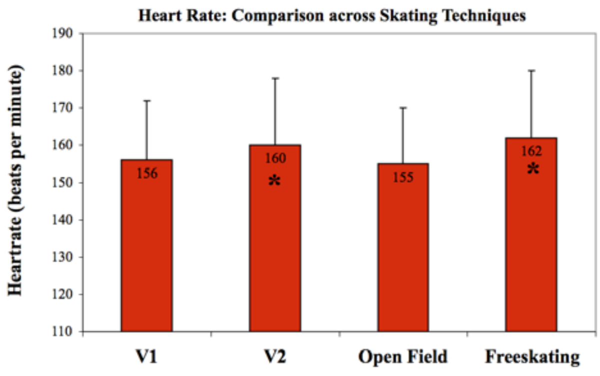
Ski skating technique choice can potentially influence economy of motion which in turn affects racing performance. Comparisons of skating techniques have demonstrated that uphill slope can influence the relative advantage of one technique versus another. On slopes greater than about 4 to 5 degrees, V1 technique may have physiological advantages over V2 technique. Mechanically this can be explained by positioning differences of skis and poles such that relatively little propulsive force can be generated from the skis using V2. Thus V2 technique demands greater upper body propulsion compared to V1 which produces more propulsive force from each leg's skating stroke. The relatively smaller muscle mass of the upper extremity compared to the legs may explain the greater physiological demands when using V2 skating on uphill terrain.

KEY WORDS: cross-country skiing, skating, mechanics

INTRODUCTION: Ski skating involves a "V" pattern where each ski is placed at an angle to the forward direction. Several typical movement patterns have evolved over the past decades which combine poling and skating movements in unique ways. Two primary skating techniques, V1 and V2, have been typically thought of as uphill and flat terrain techniques, respectively. However it has become common for ski racers to push the V2 skate on steeper uphills. As ski skating is a relatively new part of ski racing it is natural to expect an evolution toward optimal performance. Coaches and athletes question sport scientists about optimal usage of the skating techniques. The studies described in this paper aim to enhance understanding of the mechanical and physiological interactions which determine optimal performance.

Several studies have initially explored kinematic and physiological characteristics of different skating techniques under controlled conditions. For example, Boulay et al. (1995) evaluated several skating techniques across a range of slopes. On flat or modest uphills, no difference in maximum skating speed was observed. But on steeper uphills, V1 was clearly faster than V2 and open field techniques. However, maximum speed is rarely required in the relatively long distances of ski racing where aerobic and anaerobic demands at submaximal speeds are probably more closely associated with racing performance. Millet et al. (2003) measured physiological characteristics at controlled submaximal speeds on flat terrain for several skating techniques. Energy cost per kilometer and heart rate comparisons for the techniques are shown in Figures 1 and 2 below.





Figures 1 and 2: Oxygen cost per km and Heart Rate at the same submaximal speed are different depending on skating technique. Data are from Millet et al. (2003) and were collected from 12 skiers on level terrain. * V2 and Freeskating were significantly different from V1.

The results from Millet et al. (2003) suggest that V1 technique may have some advantage compared to V2 on the flat terrain of the study. However it is uncommon to see this in practice--V1 technique is rarely used on flat terrain. The current paper presents recent results comparing skating techniques across a range of slopes and speeds. Physiological characteristics combined with kinematic and kinetic measures will be used to better explain skating technique choices aimed at optimizing race performance.

METHODS: This paper describes several years of data collections involving elite level skiers from cross-country, biathlon and nordic combined national teams in Norway (see Kvamme et al. (2005) for a report of the initial physiological comparisons). All the skiers involved were well trained and very familiar with the techniques being compared in the studies. All testing was done using roller skis and a large treadmill (3 x 4 meters surface) which provided an excellent simulation of on snow skating conditions but in a controlled laboratory environment. A first experiment with six skiers involved V1 and V2 technique comparisons under six uphill conditions (3, 4, 5, 6, 7, and 8°) with speeds selected so external work was approximately constant for each slope. The 12 trials of five minutes steady-state skating were randomly distributed across two test sessions of six trials each. Heart rate, oxygen consumption, blood lactate concentration and rating of perceived exertion were measured. A second experiment involving 15 skiers compared V1 and V2 technique on a constant slope of 5 degrees with 5 speeds ranging from 2.25 to 3.25 $m \cdot s^{-1}$. Two test sessions of V1 or V2 skating were randomly assigned to days. Physiological characteristics were measured using standard procedures.
Follow-up experiments aimed to explain the physiological results based on mechanical characteristics. Eight skiers were analyzed while treadmill rollerskiing at 3 individualized speeds ranging from moderate ($2.5 \pm 0.2\ m \cdot s^{-1}$) to race speed ($3.4 \pm 0.3\ m \cdot s^{-1}$) using V1 and V2 techniques in separate sessions all on a 5 degree slope. Markers on skis, poles and body landmarks were tracked at 240 Hz using a Qualisys ProReflex system. Six cycles for each condition were analyzed using temporal and ski and pole positioning characteristics. Instrumented roller skis and poles were used to measure reaction forces. A small electronic device was carried which telemetered the force data to a computer for synchronous recording along with 3-D position data. Using ski and pole positioning to orient the resultant reaction forces in the lab coordinate system, force components were calculated. From force data, cycle characteristics, impulse, peak and average force over a cycle were determined.

RESULTS: Comparisons of V1 vs. V2 physiological characteristics across slopes were expressed as percent differences (Figure 3). On the steeper slopes, V1 was clearly advantageous compared to V2. On the lowest slope, there was a trend for V2 to be advantageous. A crossover point of relative effectiveness of about 4 to 5 degrees was observed for V1 vs. V2.

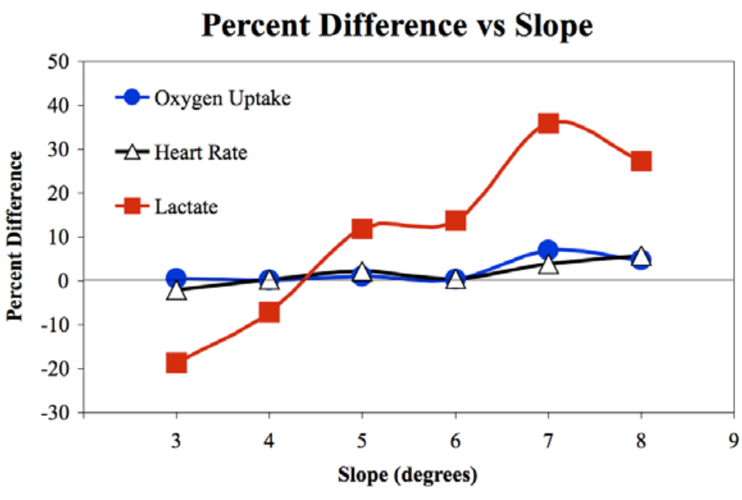
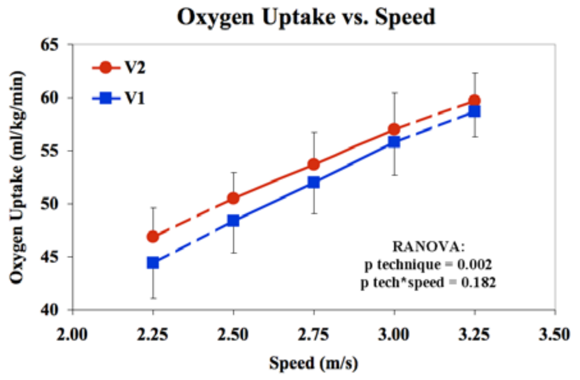
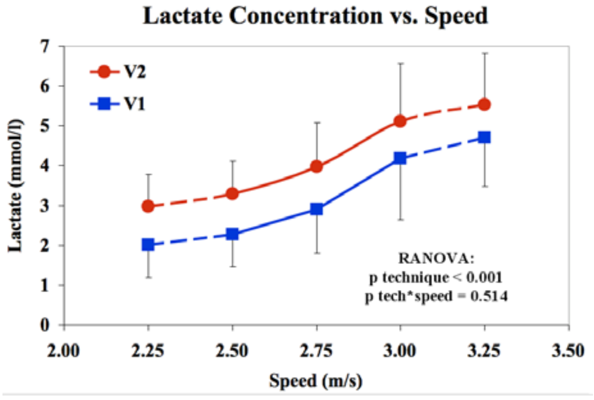


Figure 3: V1 vs V2 skating technique percent difference for VO_2, Heart Rate and blood lactate levels. Positive differences are advantageous for V1; negative differences are advantageous for V2 skating technique. On low angle slopes V2 is advantageous while on steep slopes V1 is advantageous. The relative crossover point of effectiveness is about 4-5 degrees uphill slope.





Figures 4 and 5: Oxygen uptake and blood lactate concentration comparisons for V1 and V2 skating techniques across a range of speeds. Constant slope of 5 degrees was used for all speeds. V2 had significantly greater VO2 and lactate concentration. Error bars show SD across subjects.

For both V1 and V2 skating, as speed increased by about 36%, cycle frequency and cycle length increased by 11 and 22% respectively. Ski and pole phase times systematically decreased with speed while phase percents of full cycle were nearly constant. Ski glide times for V2 are about 30% greater than for V1 while poling times for V2 are less than 70% of V1 poling times. Ski angles for V1 skating are wider than for V2: about 19 vs. 14 degrees (Figure 7). While pole positioning for V2 is similar on each side with an orientation of about 6-8 degrees from forward, V1 pole positioning is asymmetrical. Neither ski nor pole positioning changed with speed.

Ski and pole forces demonstrated consistent patterns across speeds. While peak forces increased with speed, average resultant forces were nearly constant across speed. Total propulsive force at a given speed is not dependent on which technique is used, however the distribution of propulsive force across upper and lower extremities is clearly different for V1 and V2 skating (Figure 6). For V1 technique, less than half of the propulsive force came from poling while for V2 technique about two-thirds of propulsion is due to poling forces.

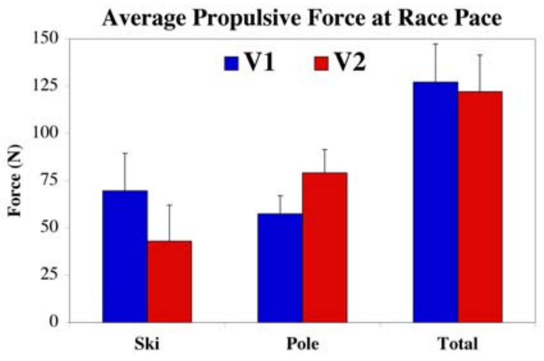


Figure 6: Propulsive force comparison for V1 and V2 skating techniques. While total propulsive force at a given speed is the same for both techniques, the upper and lower extremity demands are different. V1 generates more propulsive force from the legs through the skis while V2 generates more propulsive force through upper body poling.

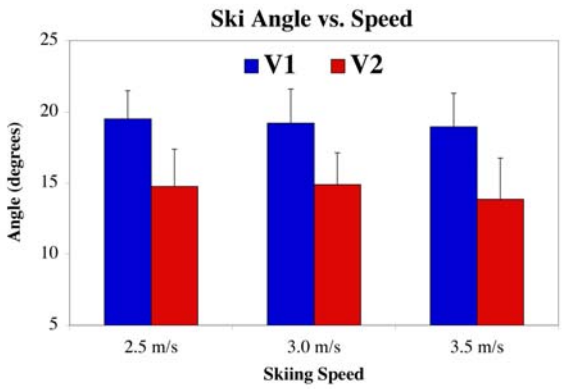


Figure 7: Ski angle comparison for V1 and V2 skating techniques across speed. V1 skating involves significantly greater ski angles with respect to the forward direction. Ski angle directly affects the proportion of the resultant force which is propulsive and explains the difference in ski propulsive force shown in Figure 6.

DISCUSSION: Across all physiological variables consistent trends comparing V1 vs. V2 were observed. As slope increased, V2 skating became increasingly demanding compared to V1 skating. At constant slope across the range of speeds, V2 was more demanding than V1 skating, independent of speed. V1 and V2 skating techniques are often used by ski racers on similar, moderate uphill terrain. These comparisons of oxygen uptake, heart rate, blood lactate concentration and perceived exertion for the two techniques at the same speed suggest that V2 skating may be disadvantageous on slopes steeper than about 4 to 5° for treadmill roller ski skating. Applying the results of this study to help optimize skier performance, coaches and skiers should refrain from thinking that V2 is simply faster than V1 skating whenever it can be accomplished. On moderate to steep uphill terrain, V2 skating may involve greater cost than V1 and have physiological consequences which could negatively influence overall race performance.

Explanation of the V1 vs. V2 physiological differences can be based on mechanical characteristics and what these imply for muscle work at a given speed. Both cycle frequency and cycle length changes are used by skiers to increase ski skating speed for V1 and V2 techniques. However the proportions of a cycle remain nearly constant across speed as do ski and pole positionings. In V2 skating the poling frequency is double the cycle frequency. On uphill slopes such as this study, V2 poling frequency at high speed (about 1.2 Hz) may be a limiting factor for steeper slopes or further speed increases as this may limit effective poling force generation. The very short duration, high velocity muscle activity required to produce poling forces in V2 skating may be the cause of elevated blood lactate level, elevated heart rate and other disadvantageous responses compared to V1 technique.

Ski propulsive force generation was observed to be greater for V1 technique than for V2. This is likely due to the wider ski angles which are characteristic of V1 skating rather than differences in the resultant forces applied to each ski. Using the relatively large muscles of the legs to generate propulsive force is probably advantageous physiologically. This favors the use of V1 technique on steeper slopes where the requirements for propulsive force are greater than on flat or modest uphill slopes.

CONCLUSION: Both V1 and V2 ski skating techniques are commonly used on moderate uphill slopes despite differences in frequency and some force characteristics. Physiological differences are apparent when slopes become steeper than about 5 degrees with V1 technique having some advantage compared to V2. These physiological differences are perhaps due to the distribution of workload across arms and legs where V2 skating places greater demands on the upper body musculature.

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