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PREDICTORS OF INTERNATIONAL SKI FEDERATION DISTANCE CROSS-COUNTRY

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PREDICTORS OF INTERNATIONAL SKI FEDERATION DISTANCE CROSS-COUNTRY RANKING

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The Internationl Ski Federation (FIS) ranks Nordic skiers internationally based on race performance. This study aimed to determine if a relationship exists between FIS rankings and performance indicators such as maximum oxygen uptake, metabolic economy, and muscular endurance test performance. Muscular endurance (sit-up + pull-up and push-up + pull-up) were the best predictors utilizing stepwise regression resampling cross-validation (66 hold out groups). The sit-up + pull-up regression was a better fit than the push-up + pull-up (R^2 = 0.506 & 0.349, p = 0.053 & 0.203, respectively). Muscular endurance test performance predicts FIS scores better than measures of oxygen consumption measures. Upper-body and core musculature may be an important determinant of performance, as it contributes to generation of propulsive forces in Nordic skiing.

KEYWORDS: FIS scores, V1 skating, V2 skating, resampling cross-validation

INTRODUCTION: International Ski Federation (FIS) scores rank cross-country skiers internationally in sprint and distance categories. During regulation events, skiers accumulate points in reference to the winner of the field, with lower scores reflecting a higher ranking (FIS, 2019). World-class Nordic skiers (i.e. those with very low FIS scores) have some of the highest VO_{2max} scores ever reported (Sandbakk & Holmberg, 2014). However, when comparing elite athletes, maximal cardiorespiratory fitness may not be the principal determinant of race performance (Millet, Perrey, Candau, & Rouillon, 2002).

Metabolic economy is an important indicator of distance event performance (Ainegren, Carlsson, Tinnsten, & Laaksonen, 2013). In Nordic skiing, the propulsive forces generated from various poling techniques may ultimately affect the metabolic economy of a skier (Millet, Hoffman, Candau, & Clifford, 1998b). Propulsive forces differ among techniques at different slopes (Millet, Hoffman, Candau, & Clifford, 1998a). Two commonly used techniques, the V1 and V2 skates, are selectively used according to terrain (Kvamme, Jakobsen, Hetland, & Smith, 2005). Skiers cover differing terrain during FIS-scoring events, thus the economy of the skier utilizing V1 and V2 skate techniques may ultimately affect overall finish place.

Propulsive ground reaction forces may not only be influenced by the economy of a skier, but also the force generation of upper body musculature. For example, short duration (≤ 60s) assessments of upper body power measured by a double poling (DP) ski-erg are positively correlated to 10km classic race speed (Alsobrook & Heil, 2009). The musculature activated during these force-generating pole plants include the rectus abdominis, latissimus dorsi, pectoralis major, and triceps brachii (Holmberg, Lindinger, Stöggl, Eitzlmair, & Müller, 2005). These muscles are also activated by push-ups, pull-ups, and sit-ups (Cogley, Archambault, Fibeger, Koverman, Youdas, & Hollman, 2005; Dickie, Faulkner, Barnes, & Lark, 2017; Parfrey, Docherty, Workman, & Behm, 2008). Although the DP technique is characteristic of greater peak poling forces than the V1 or V2 skates (Millet et al., 1998), the contribution of force generation from the upper body musculature may be similar.

Interestingly, during DP, the rectus abdominis and obliquus externus musculature appear to play a role in muscular sequencing in order to elicit advantageous propulsive ground reaction forces (Holmberg et al., 2005). As a result, the stabilization and trunk flexion capabilities of the core musculature may also be a significant indicator of performance. Thus, the purpose of the current study was to determine if a relationship exists between FIS distance scores and maximum oxygen uptake, metabolic economy of the V1 and V2 techniques, and muscular endurance test performance. To investigate similar musculature as used in poling force generation, the muscular tests included push-ups, sit-ups, pull-ups, dips, and double poling motion using a Concept 2 ski ergometer.

METHODS: Sixteen elite Nordic skiers (8 male, 8 female) performed a treadmill-controlled roller skate test to maximal exertion and two steady state workloads using both V1 and V2 skate techniques. The maximum value observed during 30s sampling intervals was recorded as the VO_{2max} (Robergs, Dwyer, & Astorino, 2010) and economy was recorded as the average of the final minute of a five-minute steady-state skate bout (men = 3.58 $m \cdot sec^{-1}$, 9% grade, women = 3.13 $m \cdot sec^{-1}$, 8% grade) (Ainegren et al., 2013). Reported muscular endurance values were computed by multiplying body mass by repetitions completed during two 60s attempts with 60s rest in between. FIS scores were extracted from the International Ski Federation "First Cross-Country List, 2018/2019" (FIS, 2019). Due to sex differences, female scores for each variable were multiplied by the fractional difference between the male and female means, thus normalizing the two populations. Without normalization, the two groups of athletes would clump together and increase the chance of a false significant regression. Analyzing males and females separately was deemed unsuitable, as it would decrease the sample size even further. Stepwise regression analysis was performed using corrected FIS distance scores as the dependent variable. Independent variables included VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$), V1 VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$), V2 VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$), push-up (kg; PUSH), pull-up (kg; PULL), sit-up (kg; SIT), dip (kg), and ski-erg absolute (Watts) and ski-erg relative (Watts/kg). Because of a low sample size (n = 16), resampling cross validation was performed according to Jensen and Kline (1994). Resampling cross validation (i.e. bootstrapping) uses repeated sampling to increase the surety of findings. In the current study, it allowed for development of multiple models with subsequent creation of a best-fit model. In total, 66 regression analyses were attempted by randomly selecting 12 of 16 participants for inclusion. The two most frequent 2-variable regression predictions were then forced using the Enter method for all 66 regression samples (132 forced regressions using SPSS Statistics v.24).
Cross-validation was performed by entering the measured values (independent variables) of the hold-out group (n = 4) into each equation. The predicted FIS scores from the equations were then compared to obtained values utilizing paired samples t-tests, to examine the differences between actual and predicted, as well as correlational analysis. This was done for each run of the resampling procedure. Results of the two forced equation models were then reported as a mean ± standard deviation of the 66 regression samples.

RESULTS: Of the initial 66 regression samples, 40 significant prediction equations ($\alpha = 0.05$) were developed. The number of independent predictors ranged from 1-3 variables (1 = 26 equations, 2 = 9 equations, 3 = 5 equations). The frequencies of primary and secondary predictors are highlighted in Figure 1.

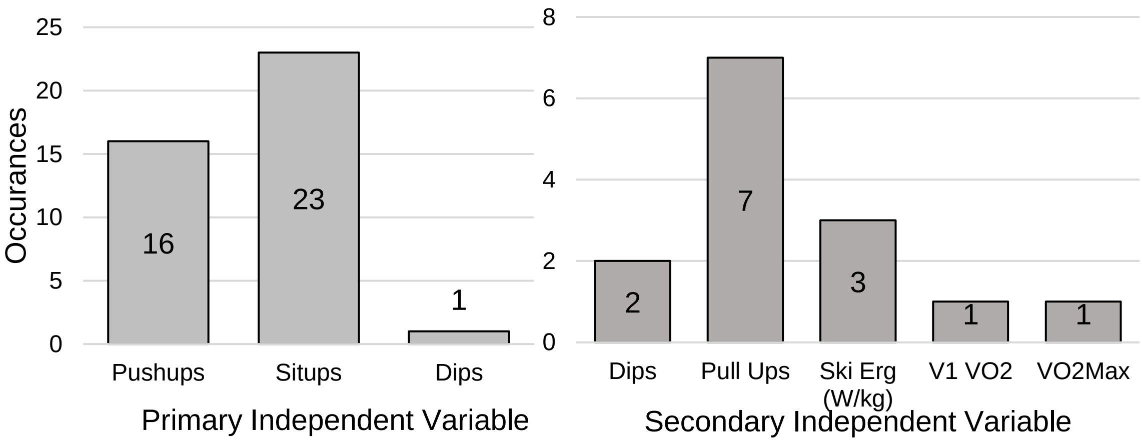

Figure 1. Of the 40 significant step-wise regressions, the occurrence frequency of primary and secondary prediction variables are presented.

Two regression model equations with two predictors were subsequently forced and cross-validated across each of the 66 hold out groups (Regression 1 = PUSH + PULL; Regression 2 = SIT + PULL). The mean results of the equation development and validation are presented in Table 1.

Table 1. The mean regression development and validation of 66 samples is presented for two forced equations: independent predictors push-up (PUSH) + pull-up (PULL), and sit-up (SIT) + PULL.

Regression Development	**PUSH + PULL**	**SIT + PULL**
R^2	0.349 ± 0.144	0.506 ± 0.097
SEE	24.640 ± 3.171	21.501 ± 3.297
Significance (α = 0.05)	0.203 ± 0.172	0.053 ± 0.044
Constant	216.086 ± 45.221	392.650 ± 47.030
Push-up Coefficient	-0.018 ± 0.006	-
SE	0.009 ± 0.002	-
Pull-up Coefficient	0.006 ± 0.005	0.020 ± 0.004
SE	0.011 ± 0.002	0.012 ± 0.003
Sit-up Coefficient	-	-0.037 ± 0.006
SE	-	0.013 ± 0.003
Validation		
Pearson Correlation	0.574 ± 0.422	0.639 ± 0.306
T-Statistic	1.216 ± 0.975	1.166 ± 1.126
P (T<=t) two-tail	0.438 ± 0.284	0.469 ± 0.275

SE = standard error; SEE = standard error of the estimate.

DISCUSSION: The frequencies of predictors in the stepwise regression analysis showed that oxygen consumption is likely not a reliable indicator of performance in elite skiers. Of the significant prediction equations, V1 economy and VO_{2max} were selected as a secondary predictor once each (Figure 1). In the current study, the elite skiers exhibited high VO_2 capacity (male = 64.1 – 77.6 $ml·kg^{-1}·min^{-1}$; unadjusted female = 54.3 – 62.2 $ml·kg^{-1}·min^{-1}$), it is therefore likely that other predictors may differentiate performance better (Sandbakk & Holmberg, 2014). VO_{2max} values were adjusted for the female participants (66.3-76.0 $ml·kg^{-1}·min^{-1}$) as a way of normalizing the data for the regression analysis, further supporting the small range in VO_{2max} results. Based on the independent variable inputs included in this study, it appears sit-ups, push-ups, and pull-ups have the greatest likelihood of predicting FIS scores (Figure 1).

The SIT + PULL model explained more of the variance in FIS performance scores than the PUSH + PULL model (R^2 = 0.506 and 0.349, respectively). The better fit of the SIT + PULL regression is also evidenced by a lower standard error of estimate and regression significance. Specifically, of the 66 SIT + PULL regression samples, 39 were significant ($p < 0.05$, average $p = 0.053$). Further, validation of the regressions indicated that the predicted values from the SIT + PULL model had a closer relationship to the measured values than the PUSH + PULL predictions (Pearson's: 0.639 and 0.574, respectively). For both regression models, the predicted vs. measured FIS scores did not have significantly different means, though small hold-out groups (n = 4) increase the chance of type II errors in these results. However, if sit-up and pull-up muscular endurance has the greatest ability to predict performance from the variables measured, it may indicate core and upper body strength are important determinants of race finish placement.

Supporting the importance of muscular endurance indices, 60 second assessments of upper body muscular endurance using a double poling ergometer positively correlates to 10 km classic skiing race speed (Alsobrook & Heil, 2009). Push-ups, pull-ups and sit-ups use similar musculature to those activated during the primary portion of the pole plant phase (Cogley et al., 2005; Dickie et al., 2017; Holmberg et al., 2005; Parfrey et al., 2008). Holmberg and colleagues investigated the DP technique, which is characteristic of greater peak poling forces than the V1 or V2 skates (Millet et al., 1998b). However, due to similar propulsive movements, the contribution of force generation from the upper body musculature may also be similar.

Due to the activation of upper body muscles during the poling phase, it is likely that these muscles contribute heavily to the differences in propulsive force generation at different grades. Pole forces measured at a 5.1° slope are greater than those at a 2.1° slope for V1 and DP techniques (Millet et al., 1998a). Inclusion of muscular endurance tests to predict FIS ranking, is thus in agreement with the propulsive demands of double poling and the V1 and V2 techniques (Alsobrook & Heil, 2009; Millet et al., 1998a). It is likely that the predictive capabilities of muscular endurance tests would vary based on grades skied by the athlete. Ultimately, muscular activation in the V1 and V2 techniques, effects of grade differences on muscular activation and several other factors could be researched to validate the results of the current study.

CONCLUSION:

Maximal oxygen uptake and the metabolic economy of V1 and V2 skating techniques may not be primary predictors of distance performance in elite cross-country skiers. Sit-up and pull-up muscular endurance provided the best prediction of FIS distance scores of those investigated in the current study. Upper body and core strength is most likely important in the generation of propulsive forces. Future research could include a larger sample size of elite skiers to enhance the conclusions of the current study.

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