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# The relationship between ventilatory threshold and repeated-sprint ability in competitive male ice hockey players

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A B S T R A C T

*Background/objective:* The relationship between ventilatory threshold (VT1, VT2) and repeated-sprint ability (RSA) in competitive male ice hockey players was investigated.
*Methods:* Forty-three male ice hockey players aged 18–23 years competing in NCAA Division I, NCAA Division III, and Junior A level participated. Participants performed an incremental graded exercise test on a skate treadmill to determine $\dot{V}O_{2peak}$, VT1, and VT2 using MedGraphics Breezesuit™ software (v-slope). Participants performed an on-ice repeated shift (RSA) test consisting of 8-maximal skating bouts, lasting approximately 25 s and interspersed with 90 s of passive recovery, to determine first gate, second gate, and total sprint decrement ($\%_{dec}$). Pearson product-moment correlations and multiple regressions were used to assess relationships between ventilatory threshold variables (VT1, VT2, Stage at VT1, and Stage at VT2) and RSA (first gate, second gate, and total course decrement).
*Results:* Stage at VT2 was the only variable substantially correlated with first gate ($r = -0.35$; $P < 0.05$), second gate ($r = -0.58$; $P < 0.001$) and total course decrement ($r = -0.42$; $P < 0.05$).
*Conclusion:* The results of this study demonstrated that VT is substantially associated with RSA, and VT2 is more strongly correlated with RSA than $\dot{V}O_{2peak}$. This study suggests that longer duration high-intensity interval training at intensities that increase workrate at VT2 may lead to possible improvements in RSA.



## Introduction

Ice hockey performance involves intermittent, high-intensity, complex movements requiring a combination of individual skills, team play, tactics, strategies, and motivational aspects.[1–3] Despite the complex nature of the sport, enhanced physical fitness would likely improve both individual and team performances. Repeated-sprint ability (RSA) is one such physical ability involved in ice hockey. Due to heavy reliance on anaerobic metabolism during repeated sprint based shifts last 30–80 s (69% anaerobic glycolysis) followed by relatively short recovery periods (31% aerobic metabolism),[4] the ability of a player to repeatedly withstand fatigue at high work intensities will lead to a competitive advantage.[5] Several authors have examined the relationship between RSA (operationalized as percent decrement or fatigue index) and aerobic fitness (operationalized as $\dot{V}O_{2max}$ or $\dot{V}O_{2peak}$) with varying results ranging from strong negative relationships to no detectable association.[5–13] While substantial relationships have been reported between RSA and $\dot{V}O_{2peak}$,[5,7,8,11–13] the relationship between RSA and other components of aerobic fitness (e.g., lactate and ventilatory threshold) are not well understood.[14]

While $\dot{V}O_{2max}$ or $\dot{V}O_{2peak}$ is considered the "gold standard" measure of aerobic fitness,[15] the lactate threshold (LT: the highest sustainable work rate where lactate production and clearance is at equilibrium),[16] and its associated measurement of ventilatory threshold (VT1/VT2: the points at which ventilation changes as a shift in lactate production occurs as work rate increases)[17,18] may be a stronger correlate of RSA than $\dot{V}O_{2peak}$.[14,15] In soccer, lactate threshold is more strongly correlated with RSA than is $\dot{V}O_{2peak}$

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($r = -0.54$ vs. $r = -0.39$, respectively).[14] These findings suggest that increased aerobic capacity at higher sustainable work rates may improve RSA by enhancing local and systemic metabolic byproduct clearance and increased aerobic energy production during repeated sprint bouts.[7,12] It may therefore be more important to develop LT than $\dot{V}O_{2peak}$ for RSA performance among intermittent high intensity sport athletes.[9] Although there are comparable physiological aspects between the both highly anaerobic and aerobic sports of soccer and ice hockey.[4,19] There still exists large physiological and game play variations between them. Such as game time length, physiological movement mechanics, and the intermittent play and intermission recovery time.[4]

If LT exhibits a stronger relationship to RSA than $\dot{V}O_{2peak}$, then LT and possibly its associated measurement VT, may be a more useful construct for coaches, practitioners, and scientists interested in evaluating training parameters that influence RSA sport performance. Training practices to optimise improvement in LT and VT are different to those targeting $\dot{V}O_{2peak}$.[20] Furthermore, LT and VT appear to demonstrate greater percent change and continue to improve with training for a longer duration than $\dot{V}O_{2peak}$.[20–24] This makes LT and/or VT an attractive candidate for athletic evaluation and programming. To date, we are unaware of any investigations looking at LT or VT in competitive ice hockey players. Population-specific evidence is needed to determine if this relationship exists in hockey athletes due to the apparent differences between soccer and ice hockey, along with the present lack of current research. The primary aim of this study was to quantify the association between VT and RSA in competitive male ice hockey players. The secondary aim was to determine if VT was a stronger predictor of RSA than $\dot{V}O_{2peak}$. It was hypothesised that VT would be substantially related to RSA and more strongly associated than $\dot{V}O_{2peak}$ due to the physiological mechanisms that allow a greater sustainable workrate at VT.

## Methods

### Participants

Forty-three, well-trained, male ice hockey players (mean ± SD: age 20.0 ± 1.4 years; height 182.5 ± 6.3 cm; body mass 84.8 ± 6.5 kg; percent body fat 11.8 ± 2.8%; relative $\dot{V}O_{2peak}$ 55.0 ± 4.5 mL/kg/min) competing at the Division I, Division III, and Junior A level participated in this study. All participants were recruited via convenience from Minneapolis, Minnesota, USA, and provided informed consent. The Institutional Review Boards of the University of Minnesota and University of North Dakota approved this study. Participants were excluded if they were absent from on-ice skating over the previous 30 days due to injury and/or if they identified their position as goaltender.

### Study design

A cross-sectional study design was used to determine the relationship between VT (VT1 & VT2) and RSA (percent decrement of first gate, second gate, and total course) during an on-ice repeated shift test in competitive ice hockey players. At the start of offseason training, athletes had their anthropometric characteristics, aerobic fitness, and on-ice repeated shift performance assessed in three separate sessions, spaced at least 48 h apart, over a 10-day period. Participants were instructed to refrain from caffeine, tobacco, and alcohol 12 h prior, and to avoid heavy exercise 24 h prior, to testing.

### Anthropometric assessment

Height (cm) and body mass (kg) were recorded using a stadiometer and the Detecto Mechanical weight scale (Webb City, MO, USA), respectively. Body density was assessed by hydrostatic weighing using the protocol described by described by Graves, Kanaley, Garzarella, & Pollock.[25] Percent body fat was estimated using Exertech Body Densitometry Systems software (Dresbach, MN, USA), which uses the Goldman (1959) equation to estimate residual lung volume and the Brožek (1963) equation to estimate percent body fat (test-retest reliability: $r = 0.95$).[25]

### Determination of aerobic fitness

A sport-specific graded exercise test was performed on a synthetic ice skate treadmill (Frappier™ Acceleration, Minneapolis, MN, USA; The Blade™ Woodway, Waukesha, WI, USA) to determine $\dot{V}O_{2peak}$, VT, and final stage completed (a work rate marker of $\dot{V}O_{2peak}$). The protocol used was previously described by Peterson et al.[5] The Ultima CPX (Medgraphics, St. Paul, MN, USA) was used to measure breath-by-breath respiratory gas volume and concentration using Breezesuite™ software (Medgraphics, St. Paul, MN, USA). The Ultima CPX compares favorably with the Douglas bag technique (average error <3%) and exhibits good test-retest reliability (coefficient of variation <5%) for both $VO_2$ and $VCO_2$ measurement.[26] The skate treadmill protocol was developed by Koepp & Janot[27] to accurately determine $\dot{V}O_{2peak}$ of ice hockey players. During this protocol, participants began skating at a 2% grade and a speed of 6.5 mph (10.5 km/h).[27] Treadmill speed then increased by 0.5 mph (0.8 km/h) every minute thereafter until a maximum speed of 10 mph (16.1 km/h) was achieved at the 8-min mark, with 1% grade increases every minute thereafter until volitional exhaustion.

### Determination of ventilatory threshold

Both ventilatory threshold (delinated as VT1) and respritory compensation, commonly known as a second ventilatory threshold (delinated as VT2), points were determined by Breezesuite™ software (Medgraphics, St. Paul, MN, USA) without manual adjustment from data collected during the graded exercise test. Breezesuite™ software's VT detection program utilizes an iterative regression and analysis of the slope $\dot{V}CO_2$ vs. $\dot{V}O_2$ to determine where $CO_2$ production begins to increase disproportionately to the $O_2$ consumption (V-Slope method). This method correlates very strongly with the lactic acidosis threshold ($r = 0.86$) and is a reproducible ($r = 0.71$) and useful non-invasive measure for the determination of VT.[28] The same method is used to identify a second inflection point, occurring after VT1, between these two parameters to identify the respritory compensation point (VT2). VT1 and VT2 were reported as oxygen consumption at VT1 and VT2 as indicated by Breezesuite™ software. The treadmill stage (work rate) was also recorded for each threshold and labeled stage at VT1 and VT2.

### On-ice repeated shift test

The on-ice repeated shift test was previously described by Peterson et al.,[5] which was designed to simulate on-ice work demands experienced during competition. The protocol was primarily designed based on data collected from the National Hockey League.[5] Participants completed eight maximal skating bouts through a fixed distance course, which took approximately 25 s to complete, with 90 s of passive recovery in between bouts. Participants performed this test in full ice hockey gear whilst holding their hockey stick. Three separate timing gates were used to assess first gate (first half: roughly the 0–10 s mark), second gate (second half: roughly the 11–25 s mark), and total fatigue decrement (total course time). Time to complete the course was measured using a TC

Speed Trap-II wireless timing system (E38720, Gill Athletics, Champaign, IL, USA). Fatigue was calculated as a percent decrement score (%dec score = (100 × [Total Sprint Time ÷ Ideal Sprint Time] − 100) for first gate, second gate, and total course.[5,29] The decrement score is a preferred method for evaluating RSA as it possesses good validity (construct and logical) and reliability that is better or on par with other techniques.[29] The coefficient of variation for the decrement score during RSA tests is approximately 30%.[29]

### *Statistical analysis*

The Statistical Package for Social Sciences (SPSS 23 for Mac; IBM, Armonk, NY. USA) was used to perform all statistical analyses. Descriptive characteristics are presented as means and standard deviations. Pearson product-moment correlation coefficients ($r$) were used to quantify the association between ventilatory thresholds and %dec scores, and were interpreted using thresholds of 0.1, 0.3 and 0.5 for weak, moderate and strong, respectively, with correlations <0.1 considered to be trivial.[30] When significant bivariate correlations were observed, sequential linear regression models were run to determine the best predictor of %dec scores during the repeated shift test. Sequential linear regression models were construction to evaluate the strength of prediction of one VT variable against one $\dot{V}O_{2peak}$ variable at a time (Step 2), while controlling for potential confounders (Step 1) with the goal of having a parsimonious model. Treadmill type and level of play were entered into the control block during sequential linear regression to control for the influence of treadmill skating surface and competitive level of play. All variables were normally distributed. Statistical significance was determined using two-tailed $P$-values and an alpha level of 0.05. Multicollinearity was not indicated in any of the multiple regression models as evidenced by variance inflation factors (VIF) < 10.[31]

## Results

Descriptive statistics for participants' oxygen consumption at ventilatory thresholds and $\dot{V}O_{2peak}$ are presented in Table 1. Ventilatory threshold variables (VT1 and VT2) were not significantly correlated with first gate or total %dec scores ($P > 0.05$) (Table 2). However, a moderate negative correlation was detected between second gate %dec score and VT1 ($r = -0.39$, $P < 0.05$) and VT2 ($r = -0.31$, $P < 0.05$). However, stage at VT1 and stage at VT2 were strong negative correlates of second gate %dec score (VT1: $r = -0.55$, $P < 0.001$; VT2: $r = -0.58$, $P < 0.001$). In addition, stage at VT2 was a moderate negative correlate of first gate %dec score ($r = -0.35$, $P < 0.05$) and total course %dec score ($r = -0.42$, $P < 0.05$).

Sequential linear regression was use to determine if ventilatory threshold variables where better predictors of RSA when compared to $\dot{V}O_{2peak}$ and final stage completed. Using sequential linear regression, stage at VT1 was a significant independent predictor of second gate %dec score ($beta = -0.56$, $P < 0.05$), whereas final stage completed was not ($beta = -0.34$, $P = 0.37$, data not shown). The squared partial correlation indicated that stage at VT1 explained approximately 11% of the variance in second gate %dec score ($P < 0.05$; data not shown). Shown in Table 3, stage at VT2 was also a significant independent predictor of second gate %dec score ($P < 0.05$), while final stage complete was not ($P > 0.05$). The squared partial correlation indicated that stage at VT2 explained roughly 14% percent of the variance ($P < 0.05$; data not shown). Shown in Table 4, stage at VT2 was also a significant independent predictor of total course %dec score ($P < 0.05$), while final stage complete was not (P > 0.05). The squared partial correlation indicated that stage at VT2 explained roughly 15% percent of the variance ($P < 0.01$; data not shown). Neither oxygen consumption values for VT1 and VT2 nor $\dot{V}O_{2peak}$ were significant independent predictors of RSA in sequential linear regression.

**Table 1**
Descriptive statistics for oxygen consumption at VT1, VT2, and $\dot{V}O_{2peak}$ for the participants ($n = 43$).

| | Mean (SD) |
|---|---|
| VT1 (mL/kg/min) | 45.3 (6.2) |
| Stage at VT1 (no.) | 6.2 (3.3) |
| VT2 (mL/kg/min) | 50.2 (5.5) |
| Stage at VT2 (no.) | 8.8 (2.6) |
| $\dot{V}O_{2peak}$ (mL/kg/min) | 54.9 (4.5) |
| Final stage completed (no.) | 9.6 (2.0) |

## Discussion

The main purpose of this study was to quantify the association between VT and RSA in competitive male ice hockey players. This study showed that both VT1 and VT2 oxygen consumption values were moderate and statistically significant correlates of second gate fatigue decrement (%dec score) assessed from an on-ice repeated shift test. Additionally, the stage (work rate) corresponding to VT1 and VT2 showed stronger correlations with second gate decrement, with stage at VT2 demonstrating the strongest associations and being the only variable that was significantly correlated with all three aspects of on-ice repeated shift performance. The secondary purpose of this study was to determine if VT was a stronger predictor of RSA than $\dot{V}O_{2peak}$. The sequential linear regression results indicated that both stage at VT1 and VT2 were stronger predictors of second gate decrement when compared to final stage completed, with beta and adjusted r-squared values indicating that stage at VT2 was the strongest predictor. Additionally, stage at VT2 was the only independent predictor of total course decrement ($P < 0.05$). As indicated by the strength of the bivariate associations and the regression results, stage at VT2 appears to be a better predictor of RSA than $\dot{V}O_{2peak}$, final stage completed, oxygen consumption at VT2, oxygen consumption at VT1 and stage at VT1.

To our knowledge, this is the first study to report on VT for competitive ice hockey players as it relates to RSA. Consistent with the results from this study, da Silva et al.[14] observed that RSA was more strongly associated with the work rate corresponding to the onset of blood lactate accumulation than $\dot{V}O_{2max}$ during a GXT in soccer players. Thus, our findings in ice hockey athletes appear to track with the findings in soccer athletes despite large differences in sport demands, threshold measurement techniques and protocols used to evaluate RSA. Furthermore, to increase the generalizability of our study results to ice hockey performance, we utilized sport-specific testing parameters including an on-ice RSA protocol that was designed to simulate on-ice work demands experienced during competition, enhancing the ecological validity of the test and our study results. Providing a mechanistic explanation for the strength of relationship between VT and RSA, da Silva et al.[14] suggested that ventilatory threshold may better reflect the peripheral aspects associated with fatigue during RSA, which has been associated with an increased ability to buffer metabolites.[32,33] Buffering metabolites appears to be one of the primary limiting factors inducing fatigue during RSA performance.[9,10]

It is unclear as to the underlying relationship between work rate at VT2 and first gate decrement performance during a repeated sprint test. To our knowledge, this association has not been previously examined. It is possible that work rate at VT2 may be more strongly related with buffering capacity associated with major pH disturbances that reduce the rate of phosphocreatine (PCr) resynthesis.[34] Future studies are needed to confirm this hypothesis. The

**Table 2**
Correlations between graded exercise test measures and performance decrement during the repeated-shift test ($n = 43$).

| | First gate decrement (%) | Second gate decrement (%) | Total decrement (%) |
|---|---|---|---|
| VT1 (ml/kg/min)[a] | −0.10 | −0.39* | −0.18 |
| Stage at VT1 (no.)[b] | −0.14 | −0.55*** | −0.28 |
| VT2 (ml/kg/min)[a] | −0.13 | −0.31* | −0.16 |
| Stage at VT2 (no.)[b] | −0.35* | −0.58*** | −0.42* |
| $\dot{V}O_{2peak}$ (ml/kg/min)[a] | −0.12 | −0.31* | −0.17 |
| Final Stage Completed (no.)[b] | −0.22 | −0.47** | −0.32* |

*significance at the 0.05 level (2-tailed).
**significance at the 0.01 level (2-tailed).
***significance at the 0.001 level (2-tailed).
[a] Bivariate correlations.
[b] Partial correlations when controlling for treadmill type.

**Table 3**
Sequential linear regression with VT2 stage and final stage completed predicting second gate decrement ($n = 43$).

| Predictors | Regression Coefficient | Standard Error | Standardised Regression Coefficient | *P*-value | $\Delta R^2$ (adjusted) |
|---|---|---|---|---|---|
| Step 1[a] | | | | | 0.01 |
| Treadmill Type | 1.60 | 1.17 | 0.25 | 0.18 | |
| Level of Play | 0.39 | 0.58 | 0.01 | 0.95 | |
| Step 2[b] | | | | | 0.30 |
| Stage at VT2 | −0.76 | 0.31 | −0.66 | 0.02 | |
| Final Stage Completed | −0.10 | 0.46 | −0.07 | 0.83 | |

*Note*. Dependent Variable: Second Gate Decrement (%).
[a] Predictors: (Constant) Treadmill Type, Level of Play.
[b] Predictors: VT2 Stage (Treadmill Test), Final Stage Completed (Treadmill Test).

**Table 4**
Sequential linear regression with VT2 stage and final stage completed predicting total course decrement ($n = 43$).

| Predictors | Regression Coefficient | Standard Error | Standardised Regression Coefficient | *P*-value | $\Delta R^2$ (adjusted) |
|---|---|---|---|---|---|
| Step 1[a] | | | | | 0.11 |
| Treadmill Type | −0.48 | 1.36 | −0.07 | 0.73 | |
| Level of Play | 1.52 | 0.67 | 0.34 | 0.029 | |
| Step 2[b] | | | | | 0.14 |
| Stage at VT2 | −0.91 | 0.36 | −0.71 | 0.02 | |
| Final Stage Completed | 0.55 | 0.53 | 0.33 | 0.31 | |

*Note*. Dependent Variable: Total Course Decrement (%).
[a] Predictors: (Constant) Treadmill Type, Level of Play.
[b] Predictors: VT2 Stage (Treadmill Test), Final Stage Completed (Treadmill Test).

relationship between VT2 and second gate decrement is likely due to stage at VT2 capturing a sustainable work rate that is associated with the work rate during the later repetitions of an RSA test. As an athlete fatigues during repeated bouts lasting roughly 25 s, maximal effort skating performance during the 11–25 s time points may drift to a greater sustainable velocity associated with VT2. Thus, athletes with greater sustainable work rate at VT2 are able to perform repeated bouts with less decrement. We speculate that this is likely due to the fact that stage at VT2 suggests an increased capacity to buffer acidosis at a higher work rate. These associations suggest that athletes with greater sustainable work rate at VT2 may have better RSA.

Unfortunately, the results of this study are not generalisable beyond the reach of competitive male ice hockey players. Relationships between aerobic fitness and RSA are likely influenced by the design of the RSA protocol. Although the sample was reasonably homogenous, participants were in different stages of their training cycle and competed at different levels of play which may pose limitations. On the other hand, this study has several strengths. It was the first study, to our knowledge, that has examined the relationship between VT and RSA in competitive male ice hockey players. This study also used validated and reliable criterion outcome measures (e.g., aerobic fitness variables) and sports-specific testing parameters (e.g., synthetic skate treadmill).

This study, although cross-sectional, indicates that athletes, coaches, and practitioners should consider implementing training programs to increase VT2, which may improve RSA and possibly the likelihood of success in ice hockey. Work rates at VT2 seem to present the best predictive power when assessing RSA. Stage at VT2 was a moderate correlate of all three aspects of the on-ice repeated shift test, suggesting that training to increase buffering capacity at higher work rates may benefit RSA. We recommend implementing longer duration high intensity interval training at intensities at or above VT2 to improve RSA.[21,35] When assessing RSA among competitive athletes, work rate intensity should be considered in conjunction with gas values for the assessment of RSA. We recommend further training-based research examining changes in training and the impact on VT2 and RSA, and possibly on-ice performance metrics.

## Conclusion

The results of this study suggest that RSA is more strongly correlated with VT than $\dot{V}O_{2peak}$, and that stage at VT2 is the strongest predictor of RSA in competitive male ice hockey players. These findings indicate that training to improve work rate at VT2, via a prolonged peak aerobic power interval training program, may improve RSA performance, even without concomitant changes in $\dot{V}O_{2peak}$.

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