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Original Article

Effects of Dynamic Warm-Up on Anaerobic Performance: A Randomized, Counterbalanced, and Cross-Over Study

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Abstract

Warming-up is a widely accepted practice performed by athletes before training and competitions, but there is little evidence determining warm-up effectiveness in improving anaerobic performance. The study aimed to determine if performing a dynamic warm-up (DW) before a Wingate Anaerobic Test (WAnT) would improve peak power output (PPO), relative peak power (RPP), mean anaerobic power (MP), and fatigue index (FI) in ice hockey players. Twenty NCAA Division II players performed the Standard National Hockey League WAnT with and without performing a DW before the WAnT (DW+WAnT or WAnT) in a randomized, counterbalanced order. The DW lasted ~6 minutes and consisted of 13 dynamic movements targeting prime movers and joints involved in ice skating. The WAnT consisted of a 30-second maximal effort performed on a mechanical cycle ergometer against a workload representing 7.5% of participants' body weight. Mean anaerobic power showed a significant increase with DW+WAnT (614.2 ± 122.3 W) compared to WAnT (592.5 ± 120.9 W) ($p = .017$). Relative peak power showed marginal trends ($p = .055$) between DW+WAnT (11.8 ± 1.5 W/kg) and WAnT (11.5 ± 1.4 W/kg). There were no differences in PPO and FI following DW+WAnT. Performing a DW before a WAnT significantly improved AC, may improve RPP, and had no detrimental effects on PPO and FI following DW. Collectively, results from this study suggest that a DW prior to the performance of a WAnT improves some anaerobic performance variables. Considering the anaerobic demands of ice hockey, the current information is valuable knowledge for coaches, strength conditioning coaches, and players supporting their preparation for assessment, training, and competition.

Keywords: Dynamic warm-up, fatigue, ice hockey, mean anaerobic power, peak power, Wingate anaerobic test

Introduction

Warming-up is a widely accepted practice performed by athletes prior to training sessions and competitions, having a critical role in optimizing overall performance (Gipson et al., 2014; McGowan et al., 2015), according to athletes and coaches (Bishop, 2003b). Despite its frequent use, there is still little evidence supporting the effectiveness of warm-ups at improving performance, particularly dynamic warm-ups (DW) (Bell & Cobner, 2011; Bishop, 2003a; Gipson et al., 2014).

Although DW varies depending on the sport, each one typically includes dynamic stretching (such as leg and arm swings), plyometrics, agility, and sport-specific movements (Aguilar et al., 2012). The purpose of a DW is to increase blood flow, improve tissue extensibility, enhance neuromuscular communication, and improve performance (Gamma et al., 2020). Specifically, in ice hockey, a DW routine before competition or practice is theorized to improve anaerobic performance at all levels from junior to professional (Bell & Cobner, 2011; Bishop, 2003a; Gipson et al., 2014). Despite this, scientific studies supporting a DW's ability to improve anaerobic performance, evidence is lacking in hockey players. Furthermore, the literature that does exist is controversial, reporting contradictory findings (Bishop, 2003b; Blazevich et al., 2018; Gipson et al., 2014) with limited consistency in the warm-up methods examined (Kendall, 2017).

Ice hockey is a dynamic game involving high-intensity intermittent efforts, including quick changes in speed, acceleration, duration, direction, and frequent body contact (Buchheit et al., 2011; Hopkins-Rosseel, 2006; Montgomery, 1988; Nightingale et al., 2013). Typically, a player is active for ~15–20 minutes of a 60-minute game with shifts lasting 30–100 seconds and recovery between shifts lasting ~4–5 minutes (Hopkins-Rosseel, 2006; Montgomery, 1988; Noonan, 2010). During a shift, aerobic demand is reflected in elevated heart rates (90 ± 2% of peak heart rate (HR) and anaerobic demand by blood lactate concentrations (range: 4.4–13.7 mmol/L; average = 8.15 ± 2.7 mmol/L) (Hopkins et al., 2001; Montgomery, 1988; Noonan, 2010).

Due to the physiological requirements of hockey, the National Hockey League uses a battery of tests at the annual combine for entry draft players, which include: body composition, strength, power, muscular endurance, anaerobic power, aerobic power,

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and hand-eye coordination (Gledhill & Jamnik, 2007). These tests are designed to predict hockey player potential; therefore, performance is essential at these events (Burr et al., 2008). Specifically, the anaerobic test selected at these events is the Wingate Anaerobic Test (WAnT), which allows for the determination of peak power output (PPO), relative peak power (RPP), mean anaerobic power (MP), and fatigue index (FI), which serve as predictors of on-ice performance (Buchheit et al., 2011; Burr et al., 2008; Nightingale et al., 2013).

Recent literature reporting the effects of DWs on anaerobic performance is controversial. Indeed, some studies report positive effects (Yamaguchi & Ishii, 2005; Yamaguchi et al., 2007), while others report no effect (Blazevich et al., 2018; Franco et al., 2012; Gipson et al., 2014; Rogan et al., 2012) or adverse effects (Franco et al., 2012; Gipson et al., 2014; Turki et al., 2012). For example, in recreationally active participants, PPO was significantly increased during WAnT after the performance of a DW (Kendall, 2017), and this same improvement was seen in highly trained males (Turki et al., 2012).

With these findings in mind, there are two major gaps in the literature; (1) can a DW improve anaerobic performance variables as measured by the WAnT and (2) are potential improvements consistent across sex and body mass index (BMI) in ice hockey players. To date, no study has reported how sex and BMI could affect anaerobic performance of ice hockey players and if sex and BMI would predict anaerobic performance following a DW intervention.

To determine the effects of DW on anaerobic performance, this study compared PPO, RPP, MP, and FI during a WAnT with and without performing a DW prior to the traditional WAnT protocol. It was hypothesized that DW would improve PPO, RPP, MP, and FI due to warm-up effects on lower leg muscles. Additionally, sex and BMI were included in a multiple regression model as covariates to identify relationships with PPO, RPP, MP, and FI in response to a DW. It was hypothesized that sex and BMI would influence PPO, MP, and FI responses to the DW intervention, but not RPP due to data normalization using individuals' body mass.

Methods

Participants

Twenty (n = 20, 10 Female) healthy NCAA Division II varsity ice hockey players volunteered to participate in the study (age: 21 ± 2 years; height: 168 ± 6 cm; weight: 72.3 ± 10.0 kg; BMI: 25.5 ± 3.0 kg/m^2). Participants were tested off-season, where they performed resistance training routines three times/week and captain run practices once a week. Participants reported no use of pharmacological drugs or aids and no injuries or other orthopedic issues that could limit their ability to perform maximal effort. Participants were instructed to have similar food intake/supplementation on testing days. They were asked to refrain from consuming alcohol, performing vigorous exercise 24 hours prior to testing, drinking caffeinated and sugary/sports beverages on testing days, and consuming a large meal within 2 hours of testing. All participants provided written informed consent, and the study was approved by the Franklin Pierce University, Institutional Review Board, agreeing with the Declaration of Helsinki.

Design

The present study compared the Standard NHL Wingate Anaerobic Test with (DW+WAnT) and without a DW. The protocol was administered on two non-consecutive days in a randomized, counterbalanced, and cross-over design (Figure 1).

Anthropometry

Height was measured by a stadiometer with a precision of .1 cm and body mass was measured by a scale with a precision of .1 kg (402KL, Health O Meter Professional, McCook, IL, USA). Body mass

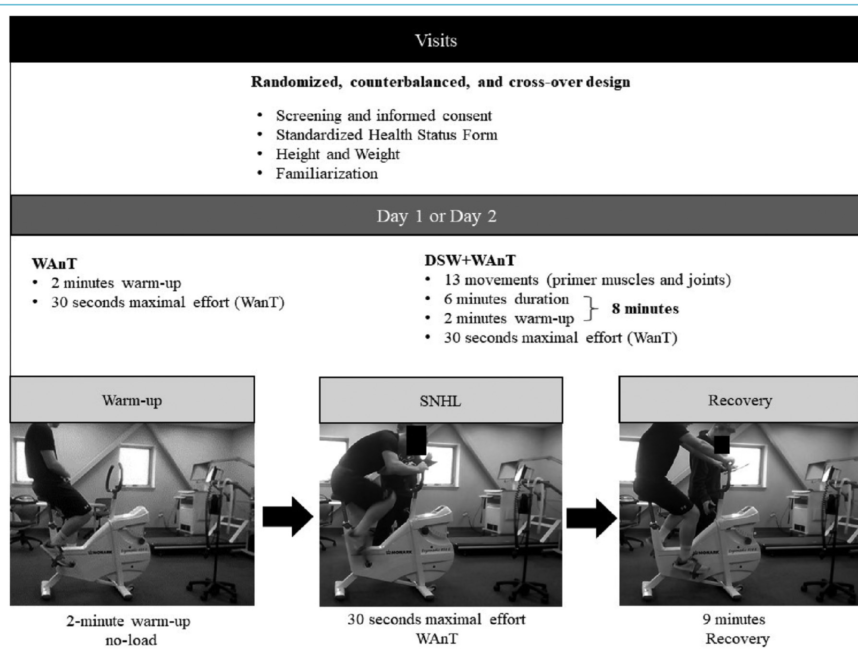


Figure 1.
Schematic Illustration of the Days of Testing. The Experimental Conditions Were Randomized and Counterbalanced in a Cross-Over Design.

index was determined using the standard formula, weight in kilograms divided by height in meters squared.

Pre-Testing

Prior to test days, heart rate (HR), systolic blood pressure (SBP), and diastolic blood pressure (DBP) were measured and recorded to ensure participants were safe to exercise and set baseline values. Systolic blood pressure and DBP were measured using a stethoscope (Lumiscope, GF Health Products, Inc., Atlanta, GA, USA) and aneroid sphygmomanometer (Dyad Medical Sourcing, LLC, Bannockburn, IL, USA) following the American College of Sports Medicine standard procedures (Kaminsky, 2014). Heart rate was continuously monitored throughout the WAnT using a heart rate monitor (Monark 828E Model, Polar Electro Inc., Finland, Kempele). Heart rate was also measured every minute after cessation of the WAnT for 9 minutes (recovery) to ensure that participants returned to their pre-test values.

Dynamic Warm-up (DW)

The DW used was the same protocol applied by the participants' strength and conditioning coach prior to training sessions. The warm-up consisted of 13 different exercises, lasting ~6 minutes that focused on the prime muscles and joints involved in skating: jumping jack series (conventional jumping jacks (1 × 10 repetitions), jumping jack seals (1 × 10 repetitions), jacks long strides (1 × 10 repetitions), jumping jacks over under (1 × 10 repetitions), lunges with T-spine rotation (1 × 5 repetitions/leg), spider lunge with hip hike (1 × 5 repetitions/leg), leg cradle (1 × 5 repetitions/leg), frog squat (1 × 5 repetitions/leg bilateral), leg lowers (1 × 5 repetitions/leg), hip circles forward (1 × 5 repetitions/leg), birddogs (1 × 5 repetitions each side), high knee skips in place (15 seconds) and high knee run in place (15 seconds). The DW intensity was selected to be at ~60% of maximal heart rate (HR_{max} = 220 – age; $\%HR_{max}$) to avoid depleting high-energy phosphate, decreasing short-term performance (Bishop, 2003b), and consequently affecting power output.

Standard National Hockey League Protocol (NHL) Wingate Anaerobic Test (WAnT)

The WAnT consisted of a 2-minute warm-up against no-load, followed by 30 seconds maximal effort sprint performed on a mechanical cycle ergometer (Monark 828E Model, Monark Exercise AB, Vansbro, Sweden) with a workload representing 7.5% of the participant's body mass. Strong verbal encouragement was given, and participants were instructed to remain seated. Following the WAnT, the resistance was removed from the cycle ergometer and participants pedaled at a self-selected cadence for a maximum of 9 minutes, where HR and BP were recorded periodically.

WAnT Anaerobic Performance Variables

The number of revolutions completed during the WAnT was recorded via a 1.0-megapixel web camera built into a Notebook computer (ASUS, PC Q502, ASUS Tek Computer Inc., Taipei, Taiwan) with time synchronization to ensure matching between the start of testing and every 5 seconds until test termination. The number of revolutions were used to calculate PPO, RPP, MP, and FI.

Peak power output was considered the highest mechanical power produced within the first 5 seconds of the WAnT. For our mechanical rope-braked ergometer, PPO was expressed in Watts and calculated as follows: PPO $= F \times d/t$, where F = force (Newtons), d = distance (m), and t = time (s). Force (F, in Newtons) was represented by the resistance applied in kilograms added to the flywheel (7.5% of the individuals' body mass). Distance (d) was calculated as revolutions multiplied by the distance around the flywheel measured in meters (d = number of revolutions × 6.12 m) divided by time (5 seconds). Relative peak power was calculated by dividing each participant's PPO by their body mass (BM): RPP = PPO/BM, where PPO is expressed in Watts and BM expressed in kilograms.

Mean anaerobic power was determined by the total work completed over the WAnT as follows: MP $= F \times d/t$; where F = force (Newtons), d = distance (m), and t = time (s). Force was represented in the same fashion as mentioned above. Distance (d) was calculated as revolutions multiplied by the distance around the flywheel measured in meters (d = number of revolutions × 6.12 m) divided by time (30 seconds). Fatigue index was determined by the percentage decline in power, comparing the highest power output (PO) with the lowest power produced in 30 seconds multiplied by 100. Fatigue index was calculated as follows: FI = (highest PO – lowest PO)/PPO × 100, where PPO and PO were expressed in Watts.

Statistical Analyses

Data are presented as mean ± standard deviation (SD). The Shapiro–Wilk test analyzed the normal distribution of the data. If data passed ($p > .05$) the normal distribution, a paired t-test was used to identify statistically significant differences between each WAnT anaerobic performance variable (PPO, RPP, MP, and FI) in the experimental conditions (DW+WAnT and WAnT); otherwise, a Wilcoxon signed-rank test was used to identify such differences. For the multiple linear regression, a preliminary analysis was performed to ensure no violation of the assumption of normality, linearity, and multicollinearity. The analysis was used to identify the relationships between the covariates sex and BMI with the WAnT anaerobic performance variables (PPO, RPP, MP, and FI) for the DW condition. The significance level was set at $p < .05$. All analyses were conducted using SigmaPlot software version 14.0 (Systac Software, Inc., San Jose, CA, USA).

Results

Baseline

Participants' baseline characteristics are presented in Table 1. There were no statistically significant differences for baseline SBP (WAnT = 120.0 ± 7.2 mmHg; DW+WAnT = 120.3 ± 7.9 mmHg; $t(19) = -.129$; $p = .90$; 95% CI [-5.29, 4.66]); baseline DBP (WAnT = 81.7 ± 6.5 mmHg; DW+ WAnT = 83.0 ± 8.5 mmHg) ($t(19) = -.534$; $p = .60$; 95% CI [-6.31, 3.68]); and baseline HR (WAnT = 72 ± 12 beats·min^{-1}); DW+WAnT = 73 ± 12 beats·min^{-}) ($t(19) = -.323$; $p = .75$; 95% CI [-9.18, 6.66]), as shown by the paired t-test.

Heart Rate

Wilcoxon signed-rank test was used to examine differences in $HR_{peak\text{-}WAnT}$ and $\%HR_{max\text{-}WAnT}$. HR_{max} was 199.3 ± 1.8 beats·min^{-1}. Peak HR at the end of the WAnT ($HR_{peak\text{-}WAnT}$) and percentage of maximal predicted HR at the end of the WAnT ($\%HR_{max\text{-}WAnT}$). Participants'

Table 1.
Participants' Baseline Systolic Blood Pressure, Diastolic Blood Pressure, Heart Rate, Peak Heart Rate at the End of the WAnT, Percentage of Maximal Predicted Heart Rate Achieved During the WAnT and Rise in HR From Baseline to Peak

Variables	WAnT	DW+WAnT	P	[95% CI] Means Difference
SBP_{bas} (mmHg)	120.0 ± 7.2	120.3 ± 7.9	.90	−5.29, 4.66
DBP_{bas} (mmHg)	81.7 ± 6.5	83.0 ± 8.5	.60	−6.31, 3.68
HR_{bas} (beats.min^{-1})	72.1 ± 11.6	73.4 ± 12.4	.75	−9.18, 6.66
$HR_{peak\text{-}WAnT}$ (beats. min^{-1})	174.4 ± 14.3	176.5 ± 15.3	.23	−7.24, 3.04
$\%HR_{max\text{-}WAnT}$ (%)	86.5 ± 10.7	88. ± 7.7	.22	−5.41, 1.35
$\uparrow HR_{bas\text{-}peak}$ (beats. min^{-1})	103.7 ± 13.2	104.5 ± 13.3	.78	−6.79, 5.19

Note: Data are mean ± standard deviation (SD). Wingate Anaerobic Test = WAnT; dynamic warm-up = DW; baseline systolic blood pressure = SBP_{bas}; baseline diastolic blood pressure = DBP_{bas}; baseline heart rate = HR_{bas}; peak heart rate at the end of the WAnT = $HR_{peak\text{-}WAnT}$; percentage of maximal predicted heart rate achieve at the WAnT = $\%HR_{max\text{-}WAnT}$; rise in HR from baseline to peak = $\uparrow HR_{bas\text{-}peak}$.

$HR_{peak\text{-}WAnT}$ (WAnT: 174 ± 14 ; DW+WAnT: 177 ± 15 beats·min^{-1}; $z = 1.234$; p(exact) = .22; 95% CI [-7.24, 3.04]) and $\%HR_{max\text{-}WAnT}$ (WAnT: 87 ± 11%; DW+WAnT: 89.0 ± 8 %; $z = 1.400$; p(exact) = .17; 95% CI [-5.41, 1.35]) did not differ between conditions. A paired t-test was used to analyze the rise in HR from baseline to peak ($\uparrow HR_{bas\text{-}peak}$) between conditions. On average, the $\uparrow HR_{bas\text{-}peak}$ did not differ between conditions (WAnT: 104 ± 13 beats·min^{-1}; DW+WAnT: 105 ± 13 beats·min^{-1}; $t(19) = -.280$; $p = .78$; 95% CI [-6.79, 5.19]) (Table 1).

Dynamic Stretching Warm-up (DW) Intensity

Heart rate values increased from 72 ± 14 to 117 ± 18 beats·min^{-1} after the DW representing an average rise in HR of 45 ± 16 beats·min^{-1}. The HR reached during DW was 59 ± 9% of participants' HR_{max}.

Anaerobic Performance Variables

There were no differences in PPO between conditions (WAnT: 831.9 ± 159.1W; DW+WAnT: 855.3 ± 168.7 W) indicated by the median post-test scores ($z = 1.724$; p(exact) = .098; 95% CI [-49.07, 2.22]) (Figure 2A) as measured by the Wilcoxon signed-rank test. The post hoc paired t-test two-tailed power analysis indicated a small effect size (Cohen's $d = .14$).

There were no differences in RPP between conditions, but there was a marginal trend (WAnT = 11.5 ± 1.3 W/kg; DW+WAnT = 11.8 ± 1.5 W/kg) indicated by the median post-test scores ($z = 1.931$; p(exact) = .055; 95% CI [-.65, .03]) (Figure 2B) as measured by the Wilcoxon signed-rank test. The post hoc paired t-test two-tailed power analysis indicated a small effect size (Cohen's $d = .22$).

Differences in FI and MP were examined using paired t-tests. There was no difference in FI between conditions (WAnT: 51 ± 9.4%; DW+WAnT: 48.9 ± 8.7%; $t(19) = 1.392$; $p = .180$; 95% CI [-.85, 4.23] (Figure 3A). The post hoc paired t-test two-tailed power analysis indicated a small effect size (Cohen's $d = .18$). Mean anaerobic power was significantly higher with a DW compared to without (WAnT = 592.6 ± 120.9 W; DW+WAnT = 614.2 ± 122.3 W; $t(19) = -2.604$; $p = .017$; 95% CI [-39.05, -4.25] (Figure 3B). The post hoc paired t-test two-tailed power analysis indicated a small effect size (Cohen's $d = .17$).

Multiple regression analysis was used to determine the relationships between sex and BMI on PPO, RPP, MP, and FI in the DW condition only. Sex was coded as 1 for males and 2 for females. For PPO, the regression model showed a significant equation, $F(2,17) = 21.48$, $p < .001$, with R^2 of .72 (Figure 4A). Predicted PPO was equal to the following: PPO (W) = 324.941 -(149.041 * Sex) + (29.521 * BMI (kg/m^2)). Peak power output increased to 29.5 W for each unit step in BMI (kg/m^2) and males produced 149 W more than females. For MP, there was a significant regression equation, $F(2;17) = 58.79$, $p < .001$, with R^2 of .87 (Figure 4B). Predicted MP was equal to the following: MP (W) = 331.028 - (143.394 * Sex) + (19.509 * BMI (kg/m^2)). Mean anaerobic power increased 19.5 W for each kg/m^2, and males produced 143 W more than females. Sex and BMI were statistically significant predictors of PPO and MP. However, there were no statistically significant differences between sex and BMI with RPP (Figure 4C) and FI (Figure 4D) ($p > .05$).

Discussion, Conclusion, and Recommendations

To the authors' knowledge, this is the first time that the effects of a DW prior to the WAnT have been assessed in ice hockey players to determine its effect on several anaerobic performance variables (PPO, RPP, MP, and FI). Consistent with our first hypothesis, MP improved with the performance of a DW prior to the WAnT ($p = .017$). Relative peak power showed trends to statistical significance with DW ($p = .055$). However, in contrast with our hypothesis, PPO ($p = .098$) and FI ($p = .180$) were similar in both experimental conditions, showing no improvements with a dynamic warm-up. Also, to date, this is the first study to determine the effects of sex and BMI on anaerobic performance of ice hockey players and how sex and BMI predicted anaerobic performance following a DW intervention. Consistent with our other hypothesis, sex and BMI were predictors of PPO and MP after DW. Peak power output increased 29.5 W, and MP increased 19.5 W for each kg/m^2. Males generated 149 more watts as measured by PPO and 143 more watts as measured by MP compared to females. Sex and BMI were not predictors of RPP or FI.

These results collectively suggest that some anaerobic performance variables (e.g. MP) are improved with a DWwhile others remain unchanged (e.g. PPO and FI). Anaerobic performance benefits resulting from a DW may be isolated to anaerobic performance over longer periods of time, rather than maximal performance capacities over shorter durations.

Consistent with previous studies (Franco et al., 2012; Gipson et al., 2014; Kendall, 2017; Rogan et al., 2012), we observed no differences in PPO and FI during the WAnT with the addition of a DW. Although we observed an improvement in MP with DW, this result is inconsistent with other studies. For example, Amani et al. (2016) concluded that neither the control condition, general warm-up (which included static stretching), or dynamic stretching condition positively impacted anaerobic performance as

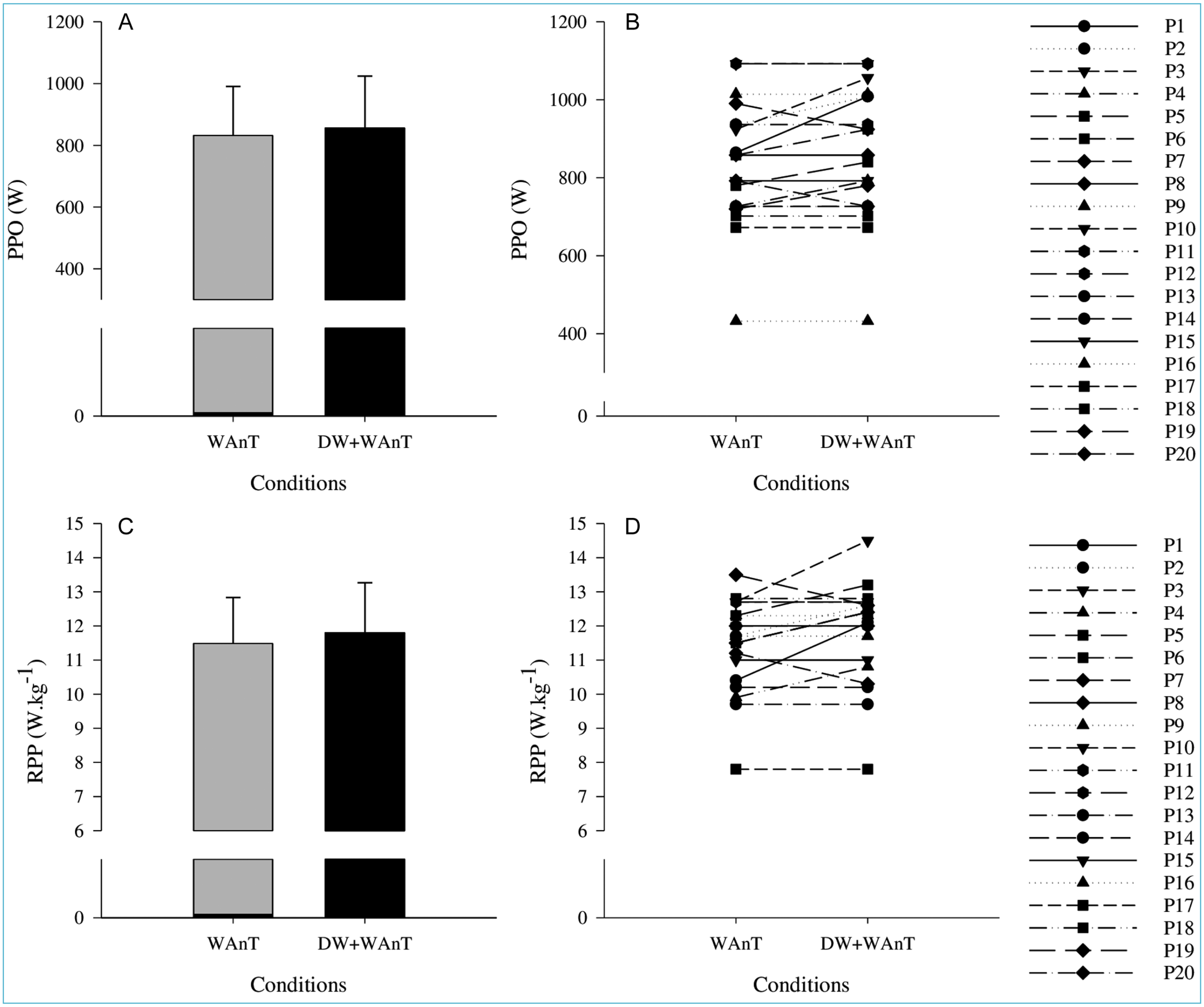


Figure 2.
Mean ± SD (A) Peak Power Output (PPO) and (B) Relative Peak Power (RPP) Comparisons Between WAnT and DW+WAnT (N = 20). (C) Peak Power Output (PPO) Individual Responses and (D) Relative Peak Power (RPP) Individual Responses Between WAnT and DW+WAnT. Each Symbol Represents One Participant (N = 20).

measured by the WAnT in recreationally active women. The discrepancy between studies could be caused by the lack of control in warm-up duration and intensity by Amani et al. (2016).

In a recent systematic review, Silva et al. (2018) reported the importance of warm-up duration and intensity for anaerobic performance improvement. They suggested that warm-ups need to be 10–15 minutes in duration and utilize progressive intensity increments ranging from 50% to 90% of maximal heart rate in order to see improvements in anaerobic performance. Our DW protocol was designed with many of the suggestions put forth by Silva et al. (2018). We considered the main joints and muscle groups used during skating and recommended intensities (Bishop, 2003a; Silva et al., 2018); however, our duration was shorter than the (~8 minutes) recommended time of 10–15 minutes (Bishop, 2003a; Silva et al., 2018).

The DW in the present study was similar to previous studies (Gipson et al., 2014; Kendall, 2017). For example, Kendall et al. (2017) compared five different conditions and their effects on Wingate performance: (1) cycling, (2) dynamic stretching, (3) static stretching, (4) dynamic stretching and cycling, and (5) static stretching and cycling. The dynamic stretching protocol was not controlled in terms of intensity or time, and it consisted of 12 different exercises, all completed over a distance of 20 m (except one exercise was done over a distance of 50 m). Although there was no significant difference between conditions on mean power, power drop, or fatigue index, the authors indicated that Cohen's effect size favored the dynamic protocol.

The discrepancies between these studies may be explained by methodological differences such as sample size (Kendall, 2017), warm-up duration, and intensity (Harmanci et al., 2014; Kendall,

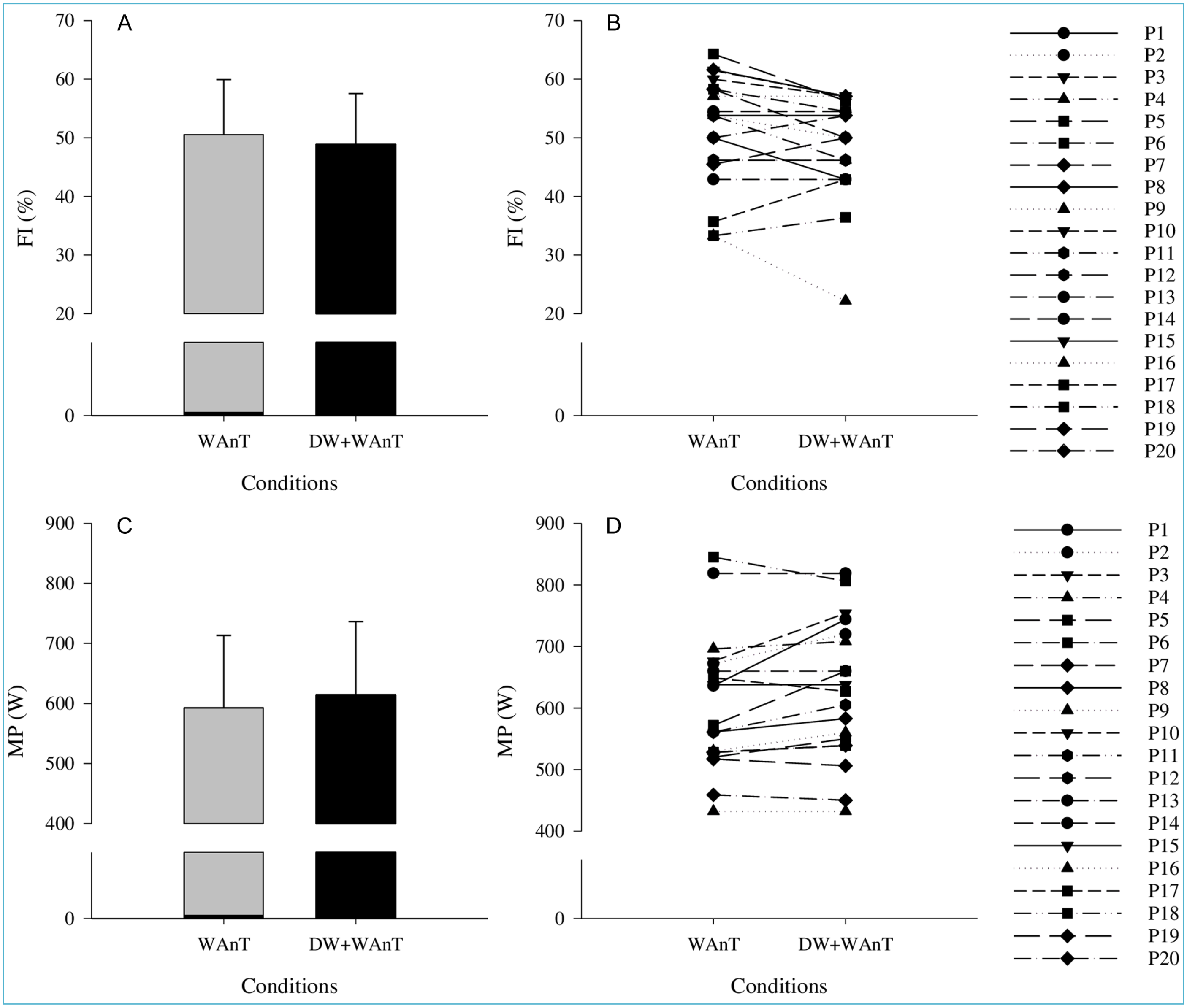


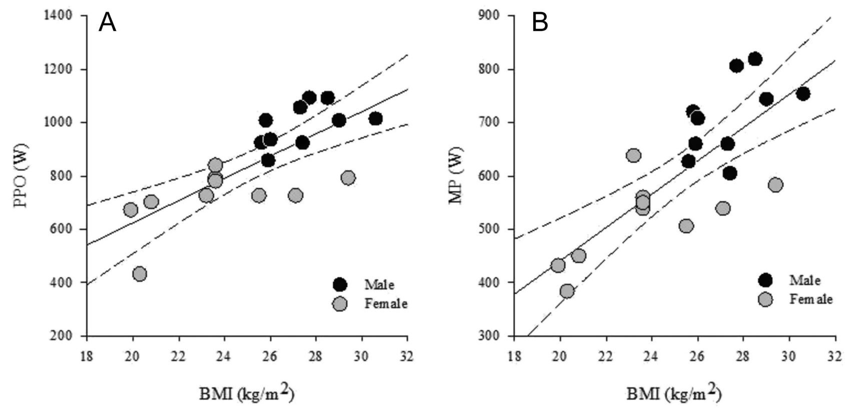
Figure 3.
*Mean ± SD (A) Fatigue Index (FI) and (B) Mean Anaerobic Power (MP) Comparisons Between WAnT and DW + WAnT (N = 20). (C) Fatigue Index (FI) Individual Responses and (D) Mean Anaerobic Power (MP) Individual Responses Between WAnT and DW+WAnT. Each Symbol Represents One Participant (N = 20). *Statistically Significant Difference Compared to WAnT (p < .05).*

2017; Turki et al., 2012), muscle groups involved (Turki et al., 2012), type of warm-up (Yamaguchi & Ishii, 2005), exercise intensity following the warm-up (i.e., maximal vs submaximal), recovery duration after warm-up (Harmanci et al., 2014), training status (Kendall, 2017), sex (Kendall, 2017), anaerobic capacity assessment (i.e., sprint, vertical jump) (Kendall, 2017), and combination of stretching with sport-specific tasks (Turki et al., 2012).

Sex differences have been studied in team sports using WAnT, where it is reported that females achieved lower peak power values than males; however, such differences have a significant contribution from body mass (Mageean et al., 2011; Perez-Gomez et al., 2008; Weber et al., 2006). To date, no study has determined how sex and BMI affect anaerobic performance of ice hockey players after DW. For this reason, sex and BMI were included in our secondary analysis in a multiple regression model as covariates to determine their relationship with PPO, RPP, MP, and FI. Multiple linear regression showed that both sex and BMI were predictors of PPO and MP, but not RPP and FI.

Other studies support our multiple regression results (Perez-Gomez et al., 2008; Weber et al., 2006). Perez-Gomez et al. (2008) and Weber et al. (2006) showed that little difference was observed when PPO from WAnT was expressed in relative terms between males and females. The authors (Perez-Gomez et al., 2008; Weber et al., 2006) also showed that absolute peak power and mean power output were higher in males than females, supporting our data as well.

In the current study, we cannot exclude the possibility that the intervention duration (~8 minutes) could have limited the positive effects of a DW on peak power and FI for some individuals



Variables	Coefficient	SE	t	P-value
Constant	324.941	254.003	-	-
Sex	-149.041	48.466	-3.075	0.007
BMI	29.521	8.220	3.591	0.002

Variables	Coefficient	SE	t	P-value
Constant	331.028	122.929	-	-
Sex	-143.394	23.456	-6.113	<0.001
BMI	19.509	3.978	4.904	<0.001

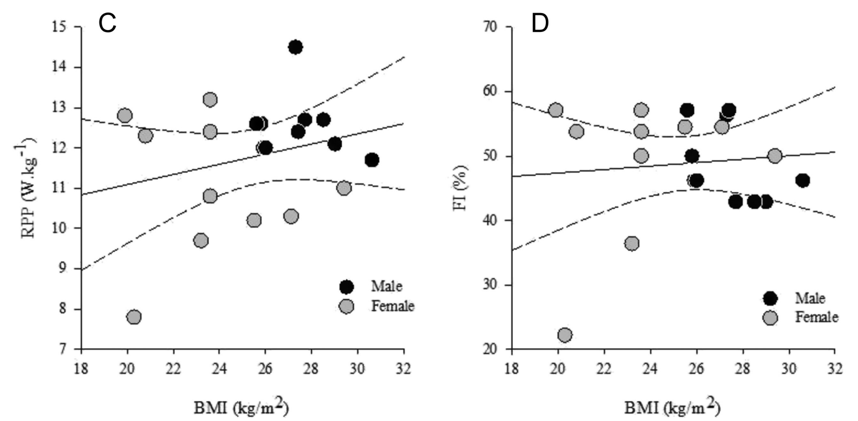


Figure 4.
Multiple Linear Regression of (A) Peak Power Output (PPO), (B) Mean Anaerobic Power (MP), (C) Relative Peak Power (RPP), and (D) Fatigue Index (FI), Including Sex and BMI Into the Model. Each Symbol Represents One Participant (N = 20). Tables Represent the Multiple Linear Regression Results From Peak Power Output (A) and Mean Anaerobic Power (B).

(Silva et al., 2018). The sample size of the study is another factor that needs to be taken into consideration. Power analysis showed that for PPO and fatigue index, considering a power of .8 and a significant level of .05, a total of 45 and 84 participants would be required in the study, respectively. Although we understand the importance of power level for statistical significance, the number of participants required for this study would not be feasible considering the number of players in a hockey team (20 players on the roaster). Despite our limitations, we believe that our study provided novel insights into the effects of dynamic stretching warm-up and ice hockey players' anaerobic performance.

Practical Application

Strength and conditioning coaches and sports coaches should use targeted DW routines prior to tests, training, and competition, providing athletes with evidence-based knowledge and guidance to educate ice hockey players on why DW routines should be performed. In particular, athletes should use a DW prior to the NHL combine as minor improvements in anaerobic performance can place them above opponents in the draft.

Prior DW can improve mean anaerobic power, may be beneficial for RPP, and have no detrimental effect on peak power and FI for ice hockey players. Sex and BMI were predictors of PPO and mean anaerobic power, but not RPP and fatigue index. It is important to mention that the DW effect on anaerobic performance was highly variable; therefore, interpretation requires caution and analysis of heterogeneity and inter-individual responses.

Peer Review: Externally peer-reviewed.

Author Contributions: Concept – A.S.; Design – A.S.; Supervision – R.V.; Resources – R.V.; Materials – R.V.; Data Collection and/or Processing – R.V., A.S.; Analysis and/or Interpretation – A.S., M.E.R., T.S., R.A., R.V.; Literature Search – A.S., M.E.R., R.A., R.V.; Writing Manuscript – A.S., M.E.R., T.S., R.A., R.V.; Critical Review – A.S., M.E.R., T.S., R.A., R.V.

Conflict of Interest: The authors have no conflicts of interest to declare.

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References

Aguilar, A. J., DiStefano, L. J., Brown, C. N., Herman, D. C., Guskiewicz, K. M., & Padua, D. A. (2012). A dynamic warm-up model increases quadriceps strength and hamstring flexibility. *Journal of Strength and Conditioning Research*, *26*(4), 1130–1141. [CrossRef]

Amani, A. R., Esmaeili, H., Aeinparast, Z., & Tari, F. (2016). Effect of different warm-up methods on anaerobic power in young women. *Annals of Applied Sport Science*, *4*(1), 17–20. [CrossRef]

Bell, W., & Cobner, D. (2011). The dynamics of distance, velocity and acceleration of power output in the 30-s Wingate anaerobic test. *International Journal of Sports Medicine*, *32*(2), 137–141. [CrossRef]

Bishop, D. (2003a). Warm-up I: Potential mechanisms and the effects of passive warm-up on exercise performance. *Sports Medicine*, *33*(6), 439–454. [CrossRef]

Bishop, D. (2003b). Warm-up II: Performance changes following active warm-up and how to structure the warm-up. *Sports Medicine*, *33*(7), 483–498. [CrossRef]

Blazevich, A. J., Gill, N. D., Kvorning, T., Kay, A. D., Goh, A. G., Hilton, B., Drinkwater, E. J., & Behm, D. G. (2018). No effect of muscle stretching within a full, dynamic warm-up on athletic performance. *Medicine and Science in Sports and Exercise*, *50*(6), 1258–1266. [CrossRef]

Buchheit, M., Lefebvre, B., Laursen, P. B., & Ahmaidi, S. (2011). Reliability, usefulness, and validity of the 30–15 intermittent ice test in young elite ice hockey players. *Journal of Strength and Conditioning Research*, *25*(5), 1457–1464. [CrossRef]

Burr, J. F., Jamnik, R. K., Baker, J., Macpherson, A., Gledhill, N., & McGuire, E. J. (2008). Relationship of physical fitness test results and hockey playing potential in elite-level ice hockey players. *Journal of Strength and Conditioning Research*, *22*(5), 1535–1543. [CrossRef]

Franco, B. L., Signorelli, G. R., Trajano, G. S., Costa, P. B., & De Oliveira, C. G. (2012). Acute effects of three different stretching protocols on the Wingate test performance. *Journal of Sports Science and Medicine*, *11*(1), 1–7. Retrieved from http://www.jssm.org.

Gamma, S. C., Baker, R., May, J., Seegmiller, J. G., Nasypany, A., & Iorio, S. M. (2020). Comparing the immediate effects of a total motion release warm-up and a dynamic warm-up protocol on the dominant shoulder in baseball athletes. *Journal of Strength and Conditioning Research*, *34*(5), 1362–1368. [CrossRef]

Gipson, A. S., Jones, J., Ritchey, E., Murphy, C., Grimes, H., & Coons, M. (2014). The acute effects of a dynamic stretching protocol on Wingate performance. *International Journal of Exercise Science*, *7*(4), 271–277. Retrieved from http://www.intjexersci.com.

Gledhill, N., & Jamnik, V. (2007). *Detailed assessment protocols for NHL entry draft players*. Toronto, Canada: York University.

Harmanci, H., Karavelioglu, M. B., Senturk, A., Kalkavan, A., & Yuksel, O. (2014). Effects of different warm-up durations on Wingate anaerobic power and capacity results. *Sportif Bakış: Spor ve Eğitim Bilimleri Dergisi*, *1*(1), 43–52.

Hopkins, W. G., Schabort, E. J., & Hawley, J. A. (2001). Reliability of power in physical performance tests. *Sports Medicine*, *31*(3), 211–234. [CrossRef]

Hopkins-Rosseel, D. H. (2006). Clinical commentary cardiovascular prevention in a high risk sport, ice hockey : Applications in wider sports physical therapy practice. *North American Journal of Sports Physical Therapy*, *1*(4), 187–194.

Kaminsky, L. A. (2014). *ACSM's health-related physical fitness assessment manual* (4th ed). Pennsylvania, USA: Wolkers Kluver/Lippincott Williams & Wilkins.

Kendall, B. J. (2017). The acute effects of static stretching compared to dynamic stretching with and without an active warm up on anaerobic performance. *International Journal of Exercise Science*, *10*(1), 53–61.

Mageean, A. L., Alexander, R. P., & Mier, C. M. (2011). Repeated sprint performance in male and female college athletes matched for VO_2 max relative to fat-free mass. *International Journal of Exercise Science*, *4*(4), 229–237.

McGowan, C. J., Pyne, D. B., Thompson, K. G., & Rattray, B. (2015). Warm-up strategies for sport and exercise: Mechanisms and applications. *Sports Medicine*, *45*(11), 1523–1546. [CrossRef]

Montgomery, D. L. (1988). Physiology of ice hockey. *Sports Medicine*, *5*(2), 99–126. [CrossRef]

Nightingale, S. C., Miller, S., & Turner, A. (2013). The usefulness and reliability of fitness testing protocols for ice hockey players: A literature review. *Journal of Strength and Conditioning Research*, *27*(6), 1742–1748. [CrossRef]

Noonan, B. C. (2010). Intragame bloodlactate values during ice hockey and their relationships to commonly used hockey testing protocols. *Journal of Strength and Conditioning Research*, *24*(9), 2290–2295. [CrossRef]

Perez-Gomez, J., Rodriguez, G. V., Ara, I., Olmedillas, H., Chavarren, J., González-Henriquez, J. J., Dorado, C., & Calbet, J. A. L. (2008). Role of muscle mass on sprint performance: Gender differences? *European Journal of Applied Physiology*, *102*(6), 685–694. [CrossRef]

Rogan, S., Blasimann, A., Steiger, M., Torre, A., & Radlinger, L. (2012). Acute effects of fast dynamic stretching on rate of force development in ice hockey players: A pilot study. *Sportverletzung Sportschaden: Organ Der Gesellschaft Fur Orthopadisch-Traumatologische Sportmedizin*, *26*(4), 207–211. [CrossRef]

Silva, L. M., Neiva, H. P., Marques, M. C., Izquierdo, M., & Marinho, D. A. (2018). Effects of warm-up, post-warm-up, and re-warm-up strategies on explosive efforts in team sports: A systematic review. *Sports Medicine*, *48*(10), 2285–2299. [CrossRef]

Turki, O., Chaouachi, A., Behm, D. G., Chtara, H., Chtara, M., Bishop, D., Chamari, K., & Amri, M. (2012). The effect of warm-ups incorporating different volumes of dynamic stretching on 10- and 20-m sprint performance in highly trained male athletes. *Journal of Strength and Conditioning Research*, *26*(1), 63–72. [CrossRef]

Weber, C. L., Chia, M., & Inbar, O. (2006). Gender differences in anaerobic power of the arms and legs: A scaling issue. *Medicine and Science in Sports and Exercise*, *38*(1), 129–137. [CrossRef]

Yamaguchi, T., & Ishii, K. (2005). Effects of static stretching for 30 seconds and dynamic stretching on leg extension power. *Journal of Strength and Conditioning Research*, *19*(3), 677–683. [CrossRef]

Yamaguchi, T., Ishii, K., Yamanaka, M., & Yasuda, K. (2007). Acute effects of dynamic stretching exercise on power output during concentric dynamic constant external resistance leg extension. *Journal of Strength and Conditioning Research*, *21*(4), 1238–1244. [CrossRef]