

## Differences in External Workload Demand between Session Types and Positions in Collegiate Men's Ice Hockey

Kevin Neeld<sup>1,2\*</sup>, Ben Peterson<sup>3</sup>, Calvin Dietz<sup>4</sup>, Thomas Cappaert<sup>1</sup>, Brent Alvar<sup>5</sup>

<sup>1</sup>Department of Health Sciences, Rocky Mountain University of Health Professions, 122 E 1700 S building 3, Provo, UT 84606

<sup>2</sup>Boston Bruins, 100 Legends Way, Boston, MA 02114

<sup>3</sup>San Francisco 49ers, 4949 Marie P DeBartolo Way (Tasman Drive), Santa Clara, CA 95054, United States

<sup>4</sup>103 Bierman Building, 516 15<sup>th</sup> Avenue SE, Minneapolis, MN, 55455, United States

<sup>5</sup>Department of Kinesiology, Point Loma Nazarene University, 3900 Lomaland Drive, San Diego, CA 92106, United States

**Corresponding Authors:** Kevin Neeld, E-mail: kevin.neeld@rm.edu

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### ABSTRACT

**Background:** Despite the importance of using a thorough understanding of competition demands to optimize preparatory strategies, there is a paucity of longitudinal workload data in ice hockey.

**Objectives:** The purpose of this study was to determine differences in workload characteristics between training and matches, and assess differences between forwards and defensemen.

**Methods:** All players from a NCAA Division I Men's Ice Hockey Team wore Catapult S5 units for all on-ice activities for two consecutive seasons. Seven workload variables (Player Load, Skating Load, Explosive Efforts, High Skate Load, Player Load·min<sup>-1</sup>, Skating Load·min<sup>-1</sup>, and Average Stride Force·lb<sup>-1</sup>) were used to quantify training and match workload characteristics.

**Results:** Compared to training, matches resulted in significantly higher Player Load (p<0.001), Total Skating Load (p<0.001), Explosive Efforts (p<0.001), High Force Strides (p<0.001), and Average Stride Force·lb<sup>-1</sup> (p=0.001), but training resulted in higher Player Load·min<sup>-1</sup> (p<0.001) and Skating Load·min<sup>-1</sup> (p<0.001). Compared to defensemen, forwards accumulated higher values in all seven workload measures, across all session types (p<.001). **Conclusion:** Matches required higher values in measures of intensity and volume, but lower work rate compared to training. Training had unique emphases based on when it occurred relative to the next match. Regardless of session type, forwards consistently produced higher workloads across all variables.

**Key words:** Hockey, Athletic Performance, Team Sports, Technology, Workload

### INTRODUCTION

Ice hockey is a high-intensity, intermittent sport requiring the integration of technical skating proficiency with the execution of complex puck skills. Matches are comprised of three twenty-minute periods, with stoppages in play resulting from scores, infractions, the puck exiting the playing area, or a goaltender covering the puck. Each team typically dresses four lines of three forwards, three pairs of two defensemen and one goaltender, with forward and defensive groupings strategically rotating throughout each period. Successful performance requires a combination of physical qualities, including speed, power, strength, and both anaerobic and aerobic conditioning (Peterson et al., 2015a, 2015b; Peyer et al., 2011; Rocznik et al., 2016).

Understanding the workload characteristics of competition is of paramount importance to appropriately prepare players for the demands of the match. Using a computerized tracking system to quantify the kinematic characteristics of players competing in an National Hockey League (NHL)

match, players covered an average total distance of 4606 ± 219m, skating 2042 ± 97m at high intensities, in an average of 17.3 ± 1.1 minutes of playing time (Lignell et al., 2018). While useful, the interpretation of this information is complicated by the gliding phase in skating, estimated to represent as much as 40.4% of on-ice movement in elite forwards (Bracko et al., 1998), as distance can accumulate without the typical demands of more active skating. Further, distance-based workload measures likely underestimate outputs associated with short-duration bursts and direction changes, collisions, and high-intensity movements like shooting (Cummins et al., 2013).

As an alternative to video-based analyses, Inertial Measurement Units (IMUs) provide a valid and reliable means of quantifying external workload in indoor sports (Chambers et al., 2015; Roell et al., 2019; Roell et al., 2018) as well as loads associated with collisions (Gabbett, 2013). Player Load (PL; MinimaxX unit, Catapult Sports, Melbourne, Australia) has been used to quantify external workload in several team

sports, including soccer, Australian Rules Football, rugby, baseball, basketball, cricket, and handball (Akenhead et al., 2016; Boyd et al., 2011; Bullock et al., 2019; McNamara et al., 2015; Read et al., 2017; Sansone et al., 2019; Scanlan et al., 2019; Wik et al., 2017). In ice hockey, PL demonstrated moderate to large test-retest reliability across nine simulated on-ice tasks (coefficient of variation: 2.2%-13.8%; intraclass correlation coefficient: 0.47-0.97)(Van Iterson et al., 2017). Given the challenges presented by the gliding phase of skating, and accurately quantifying load during short-duration high-intensity bursts, IMUs appear well-suited to quantify external workload demands in ice hockey.

Reports of on-ice workloads in hockey using longitudinal datasets are sparse. In a group of national-team level women's players monitored through an entire season, forwards produced significantly higher PL and PL/min compared to defensemen in both matches and training (Douglas, Rotondi, et al., 2019). Forwards and defensemen both accumulated higher PL in matches compared to training, but only defensemen had a higher PL·min<sup>-1</sup> in matches. In contrast, no significant differences were reported between forwards and defensemen in match or training On-Ice Load (OIL), a derivative of PL filtering out the lowest band of activity, when tracked across an entire season of men's professional hockey (Allard et al., 2020). Defensemen had lower match OIL·min<sup>-1</sup> compared to both forward positions, but higher OIL·min<sup>-1</sup> in training. Differences in gender, playing level, schedule, and workload metrics make it difficult to compare the two studies. However, given the contrasting outcomes, additional research is warranted to explore differences in loading characteristics between matches and training, and between positions in elite ice hockey. Further, despite over 130 schools supporting National Collegiate Athletic Association (NCAA) teams and roughly 1/3 of NHL players developing in NCAA programs (*About NCAA Hockey*, 2019), there is a dearth of information available describing the external workload demands at this level. Previous studies have not elucidated descriptive workload characteristics of NCAA ice hockey training and competition, identified differences between training and competition, nor generated consensus on positional differences, key pieces of information for coaches to design specific training plans to best maximize player health and performance.

Therefore, the first aim of the current investigation is to establish baseline external workload data for NCAA Division I men's ice hockey players by session type and position. Second, recognizing the potential impact of team role on playing time, we sought to identify whether top-line players exhibit different workload characteristics than bottom players. Third, we aimed to determine if workload characteristics differ between specific training types and between specific training types and matches. Finally, we sought to identify differences in workload characteristics between forwards and defensemen. Data describing the typical workloads of specific training and matches as well as positional differences will both facilitate more informed discussions between sports scientists and coaches, and help the

staff make appropriate adjustments to training and recovery interventions.

## MATERIALS AND METHODS

This study used a cross-sectional design, with a retrospective, secondary data analysis of on-ice workload measures for all rostered players across two competitive seasons. Workload was measured for each player using the OptimEye S5 unit (Catapult Sports, Melbourne, Australia) for all training and matches. Workload was characterized using measures of volume (Player Load, Skating Load), intensity (Explosive Efforts, High Force Strides, and Average Stride Force·lb<sup>-1</sup>), and work rate (Player Load·min<sup>-1</sup>, Skating Load·min<sup>-1</sup>). Sessions were characterized as a match or training, and training was further divided based on the number of days out from the next match (i.e., MD-1 = the day before, MD-2 = 2 days before, MD-3 = 3 days before, MD-4 = 4 or more days before). Players were divided into forward or defensemen position groups.

## Subjects

Participants included a convenience sample of all forwards (n=19, age 20.9 ± 1.8 years, height 180.5 ± 6.3 cm, weight 84.5 ± 6.3 kg) and defensemen (n=10, age 20.2 ± 1.4 years, height 187.6 ± 4.5 cm, weight 89.3 ± 3.9 kg) on the team roster during the 2015-2016 or 2016-2017 seasons. Eighteen players (12 forwards, 6 defensemen) were rostered both seasons. All skaters (i.e., forwards and defensemen) participating in on-ice sessions were included. Goalies were excluded from analyses due to their unique movement characteristics compared to skaters. Anonymous data with no unique identifiers was provided to the researchers for secondary analysis. This study conforms to the recommendations of the Declaration of Helsinki. However, the study was reviewed by the Institutional Review Board at Rocky Mountain University of Health Professions and qualified for exemption from IRB approval according to federal regulations at 45 CFR 46.101.

## Procedures

All players wore an OptimEye S5 monitor (Catapult Sports, Melbourne, Australia; firmware version 7.22) in a neoprene harness tight against the body in accordance with manufacturer guidelines. The monitor features a triaxial 100-Hz accelerometer, triaxial 100-Hz gyroscope, and triaxial 100-Hz magnetometer. The unit demonstrates outstanding intra-device reliability for PL with CV values < 1.0% (Nicoletta et al., 2018) and an average inter-device coefficient of variation of 1.9%, relative to the smallest worthwhile difference of 5.9% (Boyd et al., 2011). Players wore the same unit during each session to minimize error associated with inter-device reliability. Aggregated data from each sensor was processed using proprietary methods within Catapult's OpenField software (Catapult Sports, Melbourne, Australia; software version 1.17). The external workload variables used for analysis will include:

*Player Load* (PL) is the summation of force across all axes of movement and divided by 100, expressed in arbitrary units (Boyd et al., 2011). It is calculated using the equation below, where  $a_y$  = Anteroposterior acceleration;  $a_x$  = Mediolateral acceleration;  $a_z$  = Vertical acceleration.

$$\text{Player Load} = \sqrt{\frac{(a_{y(t)} - a_{y(t-1)})^2 + (a_{x(t)} - a_{x(t-1)})^2 + (a_{z(t)} - a_{z(t-1)})^2}{100}}$$

*Skating Load* (SL) is the summation of all peak accelerations per stride times athlete mass and divided by 100 (Douglas, Johnston, et al., 2019). Strides are identified using a proprietary algorithm integrating data from the accelerometer, gyroscope, and magnetometer sensors. Skating Load, expressed as a total load in arbitrary units, is calculated as:

$$\text{Skating Load} = \left( \sqrt{(a_y)^2 + (a_x)^2 + (a_z)^2} \times \text{Player Mass} \right) / 100$$

*Explosive Efforts* (EE) is calculated as a frequency count of high-intensity movements. In ice hockey, qualifying events include rapid accelerations, decelerations, and direction changes, high-intensity skating, body contact, and high-intensity shots (Douglas, Rotondi, et al., 2019). The count is derived from Inertial Movement Analysis (IMA) data. When an event is identified, the sum of the x, y area was calculated and expressed as the event magnitude (meters per second), with any movement occurring at a rate greater than  $2 \text{ m}\cdot\text{s}^{-1}$  qualifying as an explosive movement (Douglas, Rotondi, et al., 2019).

*High Force Strides* (HFS) is a frequency count of strides performed in the high force band of Skating Load. Based off recommendations from the manufacturer, this corresponds to strides that exceed 190 au for male players.

*Player Load*·min<sup>-1</sup> (PL·min<sup>-1</sup>) is a work rate metric calculated by dividing Player Load by session duration. PL·min<sup>-1</sup> provides insight into the density of work relative to the session time, which allows for more meaningful comparisons of work across sessions of different durations.

*Skating Load*·min<sup>-1</sup> (SL·min<sup>-1</sup>) is a work rate metric calculated by dividing Skating Load by session duration

*Average Stride Force*·lb<sup>-1</sup> (ASF·lb<sup>-1</sup>) is an average skating intensity metric calculated by dividing Skating Load by athlete mass. ASF·lb<sup>-1</sup> is unique compared to the other intensity measures (i.e., EE and HFS), which provide cumulative frequency counts of high-intensity measures based on reaching absolute band thresholds. In contrast, ASF·lb<sup>-1</sup> provides an indication of the average intensity across the entire session, normalized to the individual athlete's body mass, which helps account for differences in both session duration and athlete size.

Including both global (i.e., PL, EE, PL·min<sup>-1</sup>) and skating-specific (i.e., SL, HFS, SL·min<sup>-1</sup> and ASF·lb<sup>-1</sup>) workload measures provides additional insight into the contributions to loading patterns within a session. For example, a high

PL and low SL may be indicative of a larger proportion of load accumulating from passing, shooting, and contact. Data was collected only during the competitive period (October – March), excluding pre-season and post-season periods for a total of 199 total team sessions (61 matches, 138 training sessions) comprised of 3783 individual recordings across the two seasons. Training sessions were categorized based on days preceding the subsequent match (match-day difference; MD), specifically as MD-4 (n=49), MD-3 (n=31), MD-2 (n=33), and MD-1 (n=25). All training sessions four or more days prior to the subsequent match were categorized as MD-4. Match data was edited to exclude the time between periods, but includes all activity throughout each period, including rest time on the bench and stoppages in play. Training data was collected throughout the duration of training and was not edited to tease out the rest periods between drills. Upon the conclusion of each season, players were coded as either top (i.e., forwards competing on the first two lines and defensemen in the top two pairings) or bottom (i.e., forwards on the 3<sup>rd</sup> and 4<sup>th</sup> line and defensemen in the bottom pairing) based on their placement for the majority of the preceding season.

### Statistical Analyses

A MANOVA was performed comparing all seven workload variables (PL, SL, EE, HFS, PL·min<sup>-1</sup>, SL·min<sup>-1</sup>, and ASF·lb<sup>-1</sup>) between the two player groups (i.e., top vs. bottom). All workload measures were included as dependent variables and player group was included as a covariate in all subsequent analyses.

Two separate MANCOVAs were performed using session type (i.e., training vs. competition) and categorized session type (i.e., MD-4, MD-3, MD-2, MD-1), respectively, to compare differences in workload measures between sessions. Two additional factorial MANCOVAs were performed using position and session type, and position and categorized session type, respectively, to compare differences in workload measures between forwards and defensemen across each session type. Partial eta<sup>2</sup> effect sizes were interpreted as small (0.01), moderate (0.06), and large (>0.14) (Cohen, 1988).

Data analysis was performed using SPSS (IBM Corp. Released 2019. IBM SPSS Statistics for Mac, Version 26.0. Armonk, NY: IBM Corp).

## RESULTS

### Top- vs. Bottom-Line Players

Compared to bottom-line players, top-line players accumulated significantly higher PL, SL, EE, HFS, PL·min<sup>-1</sup>, and SL·min<sup>-1</sup>, while having a lower ASF·lb<sup>-1</sup> (See Table 1). Pillai's Trace revealed significant differences between groups (F=133.3, p<0.001, eta<sup>2</sup> = 0.20). A significant effect of group category was found for PL (F=25.0, p<0.001, eta<sup>2</sup> = 0.01), SL (F=167.4, p<0.001, eta<sup>2</sup> = 0.04), EE (F=78.5, p<0.001, eta<sup>2</sup> = 0.02), HFS (F=7.3, p<0.01, eta<sup>2</sup> = 0.002), PL·min<sup>-1</sup> (F=6.2, p<0.05, eta<sup>2</sup> = 0.002), SL·min<sup>-1</sup> (F=132.2, p<0.001,

$\eta^2 = 0.03$ ), and  $ASF \cdot lb^{-1}$  ( $F=212.7$ ,  $p<0.001$ ,  $\eta^2 = 0.05$ ). *Player group* was included as a covariate in all subsequent analyses. The inclusion of a covariate precludes the use of post hoc analysis if significant differences are found in MANCOVA testing. Therefore, estimated marginal means and standard errors are used to examine between-group differences.

### Training vs. Matches

The main effect of session type was significant ( $F=193.9$ ,  $p<0.001$ ,  $\eta^2 = 0.26$ ). Pairwise comparisons revealed that matches resulted in significantly higher PL (32.1,  $p<0.001$ , CI: 29.0 - 35.2), SL (268.6,  $p<0.001$ , CI: 239.0 - 298.1), EE (68.6,  $p<0.001$ , CI: 61.0 - 76.3), HFS (33.3,  $p<0.001$ , CI: 27.7 - 38.9), and  $ASF \cdot lb^{-1}$  (0.004,  $p=0.001$ , CI: 0.002-0.007), but training resulted in higher  $PL \cdot min^{-1}$  (-0.20,  $p<0.001$ , CI: -0.23 - -0.17) and  $SL \cdot min^{-1}$  (-1.85,  $p<0.001$ , CI: -2.14 - -1.56).

The main effect of specific session type was also significant ( $F=73.9$ ,  $p<0.001$ ,  $\eta^2 = 0.12$ ). Compared to matches, all four training types had significantly lower PL, SL, and EE, but higher  $PL \cdot min^{-1}$ , and  $SL \cdot min^{-1}$  values ( $p<0.001$ ). HFS were significantly higher in matches compared to MD-4, MD-2, and MD-1 sessions ( $p<0.001$ ), but not MD-3 sessions.  $ASF \cdot lb^{-1}$  was comparable between matches and MD-4, and MD-3 sessions, but significantly higher in matches compared to MD-2, and MD-1 sessions ( $p<0.001$ ). Differences between match and specific training session workload measures are presented in Table 2.

**Table 1.** Differences in workload characteristics between top- and bottom-line players

Workload Measure	Top (n=21)	Bottom (n=26)
Player Load	209.0 (46.2)	201.6 (44.5)
Skating Load	1840.0 (450.0)	1661.1 (399.8)
Explosive Efforts	413.8 (118.4)	382.2 (100.7)
High Force Strides	145.7 (84.0)	138.8 (73.1)
Player Load $\cdot min^{-1}$	2.32 (0.33)	2.29 (0.43)
Skating Load $\cdot min^{-1}$	20.5 (3.8)	19.0 (4.4)
Avg. Stride Force $\cdot lb^{-1}$	0.64 (0.03)	0.66 (0.04)

**Table 2.** Estimated marginal means (S.E.) of workload differences between matches and specific training sessions

Workload Measure	MD-4 (n=49)	MD-3 (n=31)	MD-2 (n=33)	MD-1 (n=25)
Player Load	34.0 (1.8)	10.3 (2.0)	24.0 (2.0)	67.5 (2.2)
Skating Load	273.6 (17.3)	76.6 (19.6)	226.3 (19.3)	564.7 (21.4)
Explosive Efforts	67.6 (4.5)	22.9 (5.1)	61.5 (5.0)	139.6 (5.6)
High Force Strides	30.7 (3.4)	9.2 (3.9)	34.9 (3.8)	67.7 (4.2)
Player Load $\cdot min^{-1}$	-0.1 (0.02)	-0.3 (0.02)	-0.2 (0.02)	-0.3 (0.02)
Skating Load $\cdot min^{-1}$	-1.4 (0.2)	-2.8 (0.2)	-1.2 (0.2)	-2.5 (0.2)
Avg. Stride Force $\cdot lb^{-1}$	-0.001 (0.001)	-0.002 (0.002)	0.009 (0.002)	0.015 (0.002)

Differences calculated as Match - Training. MD-1 = 1 day before match, MD-2 = 2 days before, MD-3 = 3 days before, MD-4 = 4 or more days before

### Specific Training vs. Matches

Estimated marginal means for each specific training type are presented in Table 3. Workload measures significantly differed between the training types. PL was highest in MD-3 sessions, followed by MD-2, MD-4, and MD-1, all of which were significantly different from each other ( $p<0.001$ ). SL was highest in MD-3 sessions, followed by MD-2, MD-4, and MD-1. SL on MD-2 and MD-4 sessions were similar; all others were significantly different ( $p<0.001$ ). EE were highest in MD-3 sessions, followed by MD-2, MD-4, and MD-1. EE on MD-2 and MD-4 sessions were similar; all others were significantly different ( $p<0.001$ ). HFS were highest in MD-3 sessions, followed by MD-4, MD-2, and MD-1. HFS on MD-2 and MD-4 sessions were similar; all others were significantly different ( $p<0.001$ ).

$PL \cdot min^{-1}$  was highest in MD-3 sessions, followed by MD-1, MD-2, and MD-4.  $PL \cdot min^{-1}$  in MD-3 and MD-1 sessions were similar, but significantly different from MD-4 and MD-2 ( $p<0.001$ ).  $PL \cdot min^{-1}$  in MD-4 and MD-2 sessions were similar.  $SL \cdot min^{-1}$  was highest in MD-3 sessions, followed by MD-1, MD-4, and MD-2. There were no significant differences in  $SL \cdot min^{-1}$  between MD-3 and MD-1 sessions, or between MD-4 and MD-2, but MD-3 and MD-1 sessions were significantly higher than MD-4 and MD-2 ( $p<0.001$ ).  $ASF \cdot lb^{-1}$  was highest in MD-3 sessions, followed by MD-4, MD-2, and MD-1. There were no significant differences in  $ASF \cdot lb^{-1}$  values between MD-4 and MD-3 sessions. MD-2 and MD-1 sessions were significantly different ( $p<0.05$ ). Both MD-4 and MD-3 sessions were significantly higher than MD-2 and MD-1 training ( $p<0.001$ ).

### Forwards vs. Defensemen

Tables 4a and 4b present average workload measures for forwards and defensemen for matches and training as a whole, and for each specific training type, respectively.

The main effects of position ( $F=213.5$ ,  $p<0.001$ ,  $\eta^2 = 0.28$ ), session type ( $F=165.6$ ,  $p<0.001$ ,  $\eta^2 = 0.24$ ), and the interaction between position and session type ( $F=9.5$ ,  $p<0.001$ ,  $\eta^2 = 0.02$ ) were all significant. Tests of between-subject effects revealed significant effects for all seven individual workload measures for position ( $p<0.001$ ) and session type ( $p<0.001$ ), but only for EE ( $p<0.05$ ),  $PL \cdot min^{-1}$

**Table 3.** Estimated marginal means (S.E.) of workloads during specific training sessions

Workload Measure	MD-4	MD-3	MD-2	MD-1
	(n=49)	(n=31)	(n=33)	(n=25)
Player Load	194.7 (1.3)	218.5 (1.6)	204.8 (1.6)	161.2 (1.8)
Skating Load	1671.9 (12.3)	1868.8 (15.4)	1719.2 (15.0)	1380.7 (17.5)
Explosive Efforts	380.3 (3.2)	424.0 (4.0)	386.5 (3.9)	308.4 (4.6)
High Force Strides	135.9 (2.4)	157.4 (3.0)	131.7 (2.9)	98.9 (3.4)
Player Load·min <sup>-1</sup>	2.3 (0.01)	2.5 (0.02)	2.3 (0.01)	2.4 (0.02)
Skating Load·min <sup>-1</sup>	19.8 (0.1)	21.2 (0.2)	19.5 (0.2)	20.9 (0.2)
Avg. Stride Force·lb <sup>-1</sup>	0.65 (0.001)	0.65 (0.001)	0.64 (0.001)	0.64 (0.002)

MD-1 = 1 day before match, MD-2 = 2 days before, MD-3 = 3 days before, MD-4 = 4 or more days before

**Table 4a.** Means and SDs of workload measures by position and session type

Position	Matches	Training
	(n=61)	(n=138)
Player Load		
Forwards	233.6 (40.7)	203.3 (44.7)
Defensemen	219.6 (33.8)	183.5 (41.2)
Skating Load		
Forwards	1999.5 (518.4)	1717.5 (401.7)
Defensemen	1872.4 (360.1)	1585.3 (353.7)
Explosive Efforts		
Forwards	463.3 (127.5)	387.6 (105.1)
Defensemen	422.6 (96.0)	361.1 (89.7)
High Force Strides		
Forwards	181.7 (92.9)	146.4 (79.5)
Defensemen	136.0 (55.6)	107.7 (54.1)
Player Load·min <sup>-1</sup>		
Forwards	2.2 (0.4)	2.4 (0.4)
Defensemen	2.1 (0.3)	2.2 (0.3)
Skating Load·min <sup>-1</sup>		
Forwards	18.9 (4.9)	20.7 (4.1)
Defensemen	17.7 (3.5)	19.2 (3.5)
Avg. Stride Force·lb <sup>-1</sup>		
Forwards	0.66 (0.03)	0.66 (0.03)
Defensemen	0.63 (0.02)	0.62 (0.02)

( $p < 0.01$ ), and ASF·lb<sup>-1</sup> ( $p < 0.01$ ) for the position by session type interaction (see Table 5).

Compared to defensemen, forwards accumulated significantly higher workloads across all seven measures (Table 6).

## DISCUSSION

To the best of the authors' knowledge, this is the first study reporting external workload measures for training and matches across an entire NCAA Division I ice hockey season. The two primary findings were that matches required significantly different workload outputs than training, and that forwards had higher workloads than defensemen across all measures

and session types. These findings will be explored further in the sections below.

### Matches vs. Training

In the current study, matches displayed significantly different characteristics across all seven workload measures compared to training. All four cumulative workload measures (i.e., PL, SL, EE, and HFS) were significantly higher in matches compared to training, indicating that matches required higher volumes of both total and high-intensity work. PL·min<sup>-1</sup> and SL·min<sup>-1</sup> were higher in training, which is in contrast to previous reports of higher measures of work rate in competition compared to training (Allard et al., 2020; Douglas, Rotondi, et al., 2019). This discrepancy may be reflective of population differences or philosophical differences related to the overall tempo of training design. For example, the ratio of training to matches in the current investigation was ~2.7 (138/61), compared to ~0.8 (63/76) in the men's professional players, and ~1.3 (49/37) in the women's national caliber players. More training per competition provide coaches with a greater opportunity to strategically emphasize work rate without compromising readiness for the subsequent match. Average Stride Force·lb<sup>-1</sup> measures were higher in matches, suggesting on-ice work occurred at a higher intensity during matches compared to training. Match work rates may have been lower because the data was processed to include rest time on the bench and stoppages in play, which leads to players accumulating more rest time in training than games. This emphasizes the importance of discriminating between measures of work rate and intensity.

Several interesting patterns emerged from the comparison of specific training types to matches. MD-3 sessions had similar HFS characteristics to matches, and both MD-3 and MD-4 sessions had comparable ASF·lb<sup>-1</sup> measures to matches. This highlights a workload management strategy of generally shifting from higher to lower volumes of high-intensity skating as the matches approach. Indeed, MD-3 sessions exhibited the highest PL, SL, EE, HFS, PL·min<sup>-1</sup>, and SL·min<sup>-1</sup> values compared to all three other training types. Given that the majority of MD-4 training occurred one to two days after the most recent match, managing overall volume in these sessions may allow players to better recover from the preceding matches, while the MD-3 training may

**Table 4b.** Means and SD of workload measures by position and specific training session type

Position	MD-4	MD-3	MD-2	MD-1
	(n=49)	(n=31)	(n=33)	(n=25)
Player Load				
Forwards	200.1 (45.9)	227.1 (44.2)	213.5 (36.1)	165.8 (21.7)
Defensemen	183.8 (42.8)	201.7 (40.2)	188.3 (37.9)	151.8 (20.8)
Skating Load				
Forwards	1690.4 (417.2)	1927.1 (415.5)	1788.3 (319.2)	1410.0 (206.8)
Defensemen	1616.4 (375.7)	1747.3 (355.5)	1580.9 (285.7)	1312.0 (205.7)
Explosive Efforts				
Forwards	382.5 (108.3)	439.0 (114.1)	401.6 (84.6)	313.9 (57.1)
Defensemen	372.9 (95.7)	396.7 (93.3)	356.9 (71.3)	295.7 (53.8)
High Force Strides				
Forwards	146.4 (78.8)	174.8 (90.5)	147.5 (73.8)	108.8 (54.1)
Defensemen	114.9 (55.1)	123.8 (59.3)	102.4 (48.3)	79.0 (38.5)
Player Load·min <sup>-1</sup>				
Forwards	2.4 (0.4)	2.6 (0.3)	2.4 (0.4)	2.5 (0.3)
Defensemen	2.2 (0.3)	2.3 (0.3)	2.1 (0.3)	2.3 (0.3)
Skating Load·min <sup>-1</sup>				
Forwards	19.9 (4.3)	21.8 (3.6)	20.3 (4.3)	21.4 (3.5)
Defensemen	19.2 (3.8)	19.9 (2.9)	18.1 (3.1)	19.9 (3.5)
Avg. Stride Force·lb <sup>-1</sup>				
Forwards	0.67 (0.03)	0.67 (0.03)	0.66 (0.03)	0.65 (0.03)
Defensemen	0.63 (0.03)	0.62 (0.02)	0.62 (0.02)	0.61 (0.02)

MD-1 = 1 day before match, MD-2 = 2 days before, MD-3 = 3 days before, MD-4 = 4 or more days before

**Table 5.** Between-subject effects for position, session type, and the interaction between position and session type

	Workload Measure	F	P-value	eta <sup>2</sup>
Position	Player Load	113.7	<0.001	0.03
	Skating Load	89.5	<0.001	0.02
	Explosive Efforts	81.6	<0.001	0.02
	High Force Strides	215.5	<0.001	0.05
	Player Load·min <sup>-1</sup>	185.3	<0.001	0.05
	Skating Load·min <sup>-1</sup>	103.1	<0.001	0.03
	Avg. Stride Force·lb <sup>-1</sup>	1076.6	<0.001	0.22
Session Type	Player Load	383.2	<0.001	0.09
	Skating Load	276.4	<0.001	0.07
	Explosive Efforts	250.3	<0.001	0.06
	High Force Strides	109.9	<0.001	0.03
	Player Load·min <sup>-1</sup>	185.8	<0.001	0.05
	Skating Load·min <sup>-1</sup>	146.0	<0.001	0.04
	Avg. Stride Force·lb <sup>-1</sup>	13.2	<0.001	0.003
Position x Session Type	Player Load	2.6	0.104	0.001
	Skating Load	0.04	0.835	<0.001
	Explosive Efforts	3.9	0.048	0.001
	High Force Strides	1.7	0.197	<0.001
	Player Load·min <sup>-1</sup>	9.7	0.002	0.003
	Skating Load·min <sup>-1</sup>	0.2	0.696	<0.001
	Avg. Stride Force·lb <sup>-1</sup>	7.9	0.005	0.002

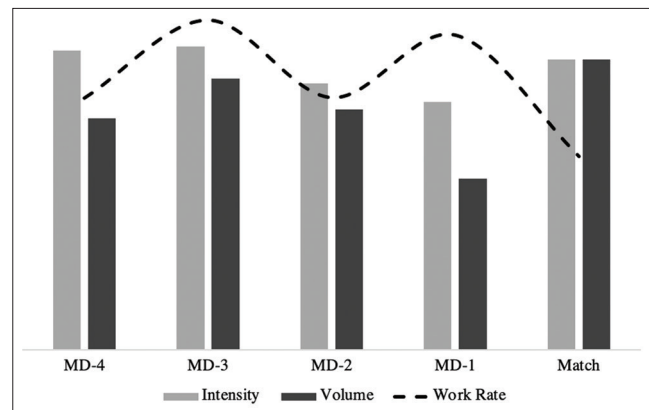
**Table 6.** Estimated marginal means (S.E.) of workload differences between forwards and defensemen

Workload Measure	Difference
Player Load	17.7 (1.7)
Skating Load	149.6 (15.8)
Explosive Efforts	37.0 (4.1)
High Force Strides	43.1 (2.9)
Player Load·min <sup>-1</sup>	0.19 (0.01)
Skating Load·min <sup>-1</sup>	1.6 (0.2)
Avg. Stride Force·lb <sup>-1</sup>	0.037 (0.001)

provide the optimal spacing between the preceding and subsequent matches to perform the highest volumes of high-intensity work. Training the day before the match exhibited the lowest cumulative workload measures of the four training types, but a high work rate, similar to MD-3 sessions. A general model for the fluctuations of intensity, volume, and work rate for each session type is displayed in Figure 1.

### Forwards vs. Defensemen

Forwards displayed higher values than defensemen in all workload measures across all session types. During matches, teams dress four lines of three forwards, and three pairs of defensemen. With fewer players to rotate, defensemen predictably accumulate more time on the ice than forwards. Consequently, it would be reasonable to expect defensemen to have higher PL, SL, PL·min<sup>-1</sup> and SL·min<sup>-1</sup> values compared to forwards, as the increased time on ice provides more opportunities to accumulate higher volumes of work, and also less inactive time, which would inflate work rates. For example, NHL League defensemen averaged 47% more ice time and covered 29% more total distance compared to forwards (Lignell et al., 2018). However, forwards covered 55% and 33% more distance in sprint and very fast skating speeds. Forwards producing higher values across all workload measures in the current study may be explained by the discrepancy in the intensity of on-ice work between the two positions. Forwards produced significantly higher values across all three measures of intensity (EE, HFS, and ASF·lb<sup>-1</sup>), across all session types. In support of this, despite no differences in total distance covered between positions, forwards competing in elite international U-20 competitions covered significantly greater distances at very fast and sprint speed thresholds, whereas defensemen covered greater distances within very slow, slow, and moderate speeds (Douglas & Kennedy, 2020). Similarly, across an American Hockey League season, forwards performed at a higher relative intensity in matches compared to defensemen, but the total load was similar across positions (Allard et al., 2020). The higher intensity outputs are apparently sufficient to cause forwards to accumulate higher total training volumes and higher work rates, despite the decreased exposure time compared to defensemen.

**Figure 1.** Model of intensity, volume, and work rate fluctuations through a typical match-cycle

### Limitations of Study

The exact workload patterns observed in the current study are likely a reflection of both the playing level and the team's coaching philosophy, and therefore may not be generalizable to other organizations. The team followed a consistent schedule of training throughout the week and back-to-back matches on the weekend. This schedule is similar for most NCAA hockey programs and many youth organizations, but not professional teams whose schedules rarely allow for -3 and -4 training days. While the exact workload patterns may not be generalizable to other levels, the theme of varying intensity, volume and work rate systematically to maximize preparation for competition is still relevant.

### Practical Application

There are several key takeaways from this study that can help facilitate a more targeted approach from practitioners working in ice hockey. Teams carrying fewer defensive pairs than forward lines may have defensemen accumulate higher work rates and volumes in training compared to forwards, which does not appropriately match competition demands. To counteract inflated defensive workloads, both volume and work rate measures can be live monitored to help guide coaches in interspersing brief rest periods between drill repetitions or rotate players who are inadvertently performing excessive work. Further, designing training to feature higher volumes of high-intensity work three days before competition may be optimal to allow sufficient recovery time prior to the next match. Emphasizing a high work rate, but low volume in MD-1 sessions may have a stimulatory effect to help players compete at a high work rate but minimize residual fatigue. In a return to play setting, the performance and medical staffs can better contextualize an individual player's readiness to meet the position-specific workload demands of both training and competition and use position-specific competition loads to reverse engineer a progressive on-ice reconditioning phase.

### CONCLUSIONS

Quantifying the workload characteristics of competition and training is a fundamental step in better understanding the

demands of the sport and assessing the specificity of training. The current study highlights key positional differences, namely that forwards perform significantly more high intensity work and accumulate higher total volumes of work compared to defensemen. While matches required higher values in measures of intensity and volume than training, specific training more closely approximated intensity and work rate measures of competition. Strategically manipulating intensity, volume, and work rate throughout the week provides an opportunity to emphasize specific qualities of competition, while also allowing sufficient recovery time prior to the subsequent competition.

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