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Research Article

Maintenance of External and Internal Loads, and Physical Performance during an Overtime Championship Game in Men's Varsity Ice Hockey

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Abstract

This study quantified novel local positioning system (LPS) external load metrics and internal load (heart rate-derived training impulse, TRIMP) during the unique environment of an ice hockey championship (overtime) game across three periods of regulation time (60 min) and two periods of overtime (40 min). Data were collected from 15 male varsity ice hockey players (6 defence, 9 forwards; 22.0 ± 0.9 yrs, 84.1 ± 4.6 kg, 181.2 ± 4.4 cm). LPS metrics included skating distance, peak skating speed, peak acceleration/deceleration, and number of accelerations/decelerations, sharp/wide turns, skating transitions, changes of direction, and impacts. The mean skating distance was maintained across periods 1-5 (2110 ± 464, 2126 ± 490, 2012 ± 614, 2315 ± 649, and 2093 ± 549 m). Peak speed (30.25 ± 2.08, 30.78 ± 1.72, 30.67 ± 2.20, 29.99 ± 2.06 and 30.37 ± 2.18 km/hr) and TRIMP (38.47 ± 14.83, 32.67 ± 15.39, 33.43 ± 19.18, 36.39 ± 18.29, 31.41 ± 11.89 AU) were also maintained from period 1 to 5. Forwards had greater peak skating speed, skated further in high-intensity speed zones (>21 km/hr), and had greater TRIMP vs. defence in most periods and the entire game ($p<0.048$). In summary, this study measured novel and objective LPS-derived external load and TRIMP internal load during an extended men's varsity ice hockey game and remarkably, there were no decreases in players' workload in the third period or two overtime periods. This suggested a high level of players' fitness and potentially high motivation associated the championship game.

ABBREVIATIONS

GPS: Global Positioning System; LPS: Local Positioning System; NHL: National Hockey League; AHL: American Hockey League; TOI: Time-on-ice; TRIMP: Training Impulse

INTRODUCTION

Ice hockey is a team sport that requires repeated high-intensity bouts of skating, physical contact, and tactical skill, separated by short periods of recovery [1-3]. Research investigating ice hockey has examined player characteristics and fitness [4,5], nutrition and hydration [6,7], and risk of injuries and concussions [8-10] common to this intense stop-and-go sport. However, limited research has attempted to quantify the players' physical and physiological demands (workload) in ice hockey.

Heart rate-derived training impulse (TRIMP) is one of the most common measures used to quantify the internal load in ice hockey players [11-16], whereas examination of the external workload of ice hockey players has traditionally relied on time-motion and video analysis [17,18]. More recently, technological advancements have allowed for the measurement of external load in ice hockey using accelerometers [3,19-23] that provide information pertaining to external load using machine learning algorithms (acceleration load, PlayerLoad, skating load, and explosive efforts) [20]. However, they are unable to provide positional (location on playing surface), and indirectly speed and acceleration, information that can be collected with outdoor global positioning systems (GPS).

Most recently, newly developed local positioning systems (LPS) have been able to provide GPS-like measures collecting data for indoor sports, which has been validated in several situations when compared to GPS, video x and y coordinate position, and an infra-red camera system [23-28]. Furthermore, two new studies using LPS in ice hockey have provided on-ice player tracking information that can provide initial external load demands, including on-ice position, distance, speed, and acceleration during games [3,22].

Studies examining internal and external load of hockey players have reported differences in load when comparing periods and positions. Analysis of internal load in games outlined positional differences in TRIMP between periods and sexes [14], and positions, phases of season, and weekly training sessions [15]. External loads were higher in the first period compared to the third period when measuring external load with video analysis in National Hockey League (NHL) players [29], accelerometry in elite female and American Hockey League (AHL) players [19,20], and LPS in elite junior Danish and Canadian U20 male players [3,22]. It has also been reported that forwards skated at a greater intensity than defence [19,21,29,30].

Given the limited research using this novel technology, LPS-derived external load in ice hockey can be further detailed in different levels of play, game situations, and in both sexes, to advance topics surrounding optimal player health and performance. Therefore, the purpose of this study was to quantify and compare player statistics, novel LPS external load metrics, and TRIMP during the unique environment of a male varsity ice hockey championship (overtime) game across three periods of regulation time (60 min) and two additional periods of overtime (40 min) for positions and all players. Although this is the first study of its kind for a varsity population in a game of this magnitude, it was hypothesized that changes in external load would decrease in period 3 vs period 1, with further decreases in the overtime periods 4 and 5. It was also hypothesized that TRIMP would increase in later periods to maintain external workload, and that forwards would have greater intensity of external load when compared to defence throughout the 5 periods.

MATERIALS AND METHODS

Subjects

Fifteen male varsity ice hockey players participated in this investigation during a provincial championship game. The mean (± SD) age, weight, and height of the subjects were 22.0 ± 0.9 yrs, 84.1 ± 4.6 kg, and 181.2 ± 4.4 cm, respectively. The analysis of results focused strictly on 6 defence and 9 forwards with regular playing time. Players were informed of all protocols, requirements, and risks, both verbally and in writing, prior to obtaining oral and written consent. The study was part of a longitudinal athlete surveillance study approved by the university research ethics board and conformed to the Declaration of Helsinki.

Procedures

Study design: All data were collected for a single playoff championship game during the 2019-2020 season, which included three regulation and two overtime periods (20 min each). Regarding the competitive nature of the environment, the game remained scoreless until the third period, where both teams scored one goal. The game-winning goal was scored by the team that participated in the research, which concluded the game <2 min into the third overtime period. Player statistics were recorded through analysis of video captured by the corresponding university league. On-ice player tracking measures (external load) were collected using an ultra-wideband LPS (Kinexon, Munich, Germany). Internal load was captured using a Polar heart rate sensor (Polar OH1, Polar Electro OY, Kempele, Finland).

Player statistics: Video analysis was used to determine time-on-ice (TOI), shift length, and number of shifts, shots-on-net, bodychecks delivered, and blocked shots. TOI and shift length were recorded for all players using a stopwatch and the remaining measures were manually tabulated.

LPS-derived external load: The LPS incorporated specific local network access, one Power over Ethernet switch and one server (located in the media booth), 16 anchors (secured to the rafters), and one sensor for each participant (secured in a patch on the posterior side of the shoulder pads near the superior 1/3 of the scapula) (Figure 1). Communication between anchors and the player sensors (though ultra-wideband channels ranging from 3244.88-4742.40 MHz) allowed for collection of real-time data, which was then transmitted to the server via hardwired connection. Using the local network, the LPS platform and data

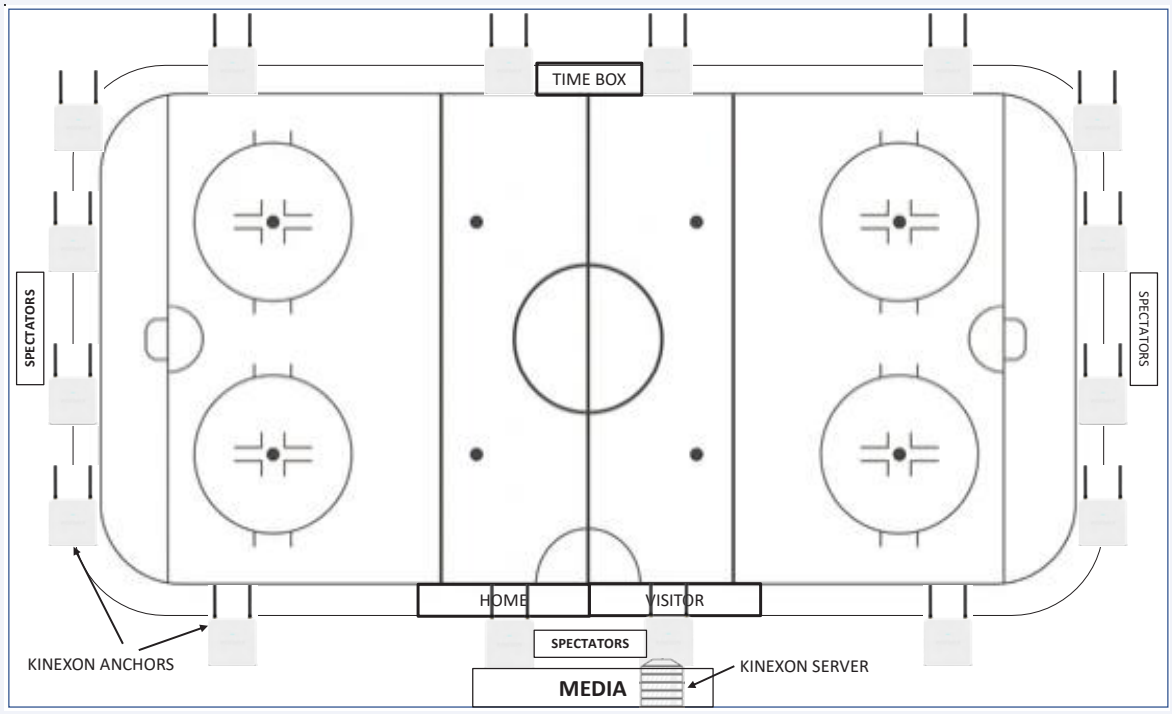

Figure 1 Schematic diagram outlining the location of one server and 16 anchors that allow for on-ice player tracking during games and practices using an ultra-wideband local positioning system (Kinexon, Munich, Germany).

(sampling rate of 20 Hz) could be retrieved on a secure computer or tablet. Definitions of external load LPS metrics were adapted from One & Media - KNX ONE Hockey Metrics (Kinexon, Munich, Germany; Table 1).

Internal load: Each player wore a heart rate sensor around the middle upper arm beneath the shoulder pad strap and was Bluetooth® connected to each LPS sensor. Banister's TRIMP [31] was used to determine an objective physiological indicator of internal load, as per other recent ice hockey research [14-16,21].

Statistical analysis

All data are presented as the mean ± SD or as counts and were analyzed using STATA/IC 15.0 software (College Station, TX) and SPSS version 26 (Armonk, NY). Q-Q plots were used to visually confirm normality. All data reported as counts are presented as descriptive and background information. A one-way repeated measures analysis of variance (ANOVA) with a Bonferroni correction for multiple comparisons tests was used to compare all means of in-game statistics, on-ice player tracking LPS metrics, and TRIMP across the 5 full periods of the game within defence, forwards, and all players. The Greenhouse-Geisser correction was used in the event that Mauchly's test of sphericity was violated. Eta squared (η) derived effect sizes were calculated for these comparisons, with (η)=0.01 indicating a small effect, (η)=0.06 indicating a medium effect, and (η)=0.14 indicating a large effect [32]. Independent sample t-tests were used to compare measures between defence and forwards within each full period and the entire game. Effect sizes for these comparisons were determined using the Cohen's d (d) assessment, with d=0.2 indicating a small effect, d=0.6 indicating a medium effect, d=1.2 indicating a large effect, and d=2.0 indicating a very large effect [33]. Statistical significance was determined by $p<0.05$.

RESULTS AND DISCUSSION

Player statistics

Player TOI ranged from 1094 to 2682 s for the entire game, while TOI in distinct periods ranged from 166 to 649 s. There were no significant differences between periods ($p=0.137$) or positions ($p>0.328$) (Table 2). The number of shifts ranged from 3 to 11 within periods and 24 to 50 for the entire game, while shift lengths ranged from 32 to 70 s. There were significant differences in average number of shifts for defence [$F(4,20) = 4.577$, $p=0.009$, $\eta=0.478$], forwards [$F(4,32) = 4.732$, $p=0.004$, $\eta=0.372$], and all players [$F(4,56) = 6.94$, $p<0.001$, $\eta=0.331$] across periods (Table 2). Defence had more shifts in periods 1 and 4 vs period 3 ($p<0.042$), while forwards (all $p<0.033$) and all players (all $p<0.008$) had more shifts in period 4 vs periods 2, 3, and 5. Similarly, average shift length was significantly different for defence [$F(4,20) = 5.061$, $p=0.006$, $\eta=0.503$], forwards [$F(4,32) = 3.002$, $p=0.033$, $\eta=0.273$], and all players [$F(4,56) = 5.67$, $p=0.001$, $\eta=0.288$] across periods (Table 2). Defence had greater average shift lengths in period 3 vs 1 ($p=0.005$), forwards had greater average shift lengths in period 5 vs 4 ($p=0.048$), and all players had greater average shift lengths (all $p<0.028$) in periods 3 and 5 vs 1, and period 4 vs 3. Defence also had greater average shift lengths than forwards in periods 3 ($p<0.001$, $d=2.410$) and 4 ($p=0.049$, $d=1.012$).

Video analysis of the game displayed that of the 38 shots taken by players on the opposing team's net, one player took none and two players took 7 shots (Table 2). Three players delivered no bodychecks and one player delivered 10 bodychecks, while 4 players blocked no shots and three players blocked three shots.

LPS-derived external load

There were no significant differences in total skating distance (ranging from 5997 to 14315 m for individual skating distance during the entire game) between positions ($p>0.158$) or periods ($p>0.065$). Total skating distances were 2110 ± 464, 2126 ± 490, 2012 ± 614, 2315 ± 649, and 2093 ± 549 m for periods 1-5, and 10013 ± 3619, 11454 ± 1751, 10878 ± 2639 m for defence, forwards, and all players, respectively. The average skating distance was 6248 ± 1500 m in the first three periods and 4408 ± 1143 in the last 2 periods.

When examining skating distances in specific speed zones, skating distance was significantly different for forwards [$F(4,32) = 4.988$, $p=0.003$, $\eta=0.384$] and all players ($F(2.45,34.30) = 4.878$, $p=0.009$, $\eta=0.258$) in the very slow speed zone (1.0-10.9 km/hr) (Figure 2). Forwards skated further in period 4 vs periods 1 ($p=0.007$) and 5 ($p=0.006$), and all players skated further in

Table 1. Definitions of external load LPS metrics adapted from One & Media - KNX ONE Hockey Metrics (Kinexon, Munich, Germany).

LPS Metric	Definition
Skating distance	Distance covered based on changes in on-ice position (total and separated into specific speed zones based on previous ice-hockey literature [21,29])
Peak skating speed	Maximum instantaneous speed based on changes in on-ice position and time
Peak acceleration	Maximum instantaneous acceleration based on changes in on-ice speed and time
Peak deceleration	Maximum instantaneous deceleration based on changes in on-ice speed and time
Number of accelerations and decelerations	Frequency of player accelerations and decelerations >2 m/s2
Sharp turns	Turns with a radius <2 m
Wide turns	Turns with a radius >2 m
Skating transitions	Number of transitions from forward-to-backward or backward-to-forward skating
Number of changes of direction	Frequency of changes in on-ice motion direction following a deceleration and prior to an acceleration
Number of impacts	Number of impacts: frequency of collisions (triggered by a G force >3 g on the sensor) with the ice, boards, or another player
Abbreviations: LPS: Local Positioning System	

Table 2. Player statistics across periods and positions identified using video analysis.

	Period 1	Period 2	Period 3	Period 4	Period 5	Game Total
Time-on-ice (sec)						
Defence	367 ± 115	374 ± 110	380 ± 153	405 ± 202	383 ± 151	1925 ± 727
Forwards	345 ± 70	391 ± 81	374 ± 41	397 ± 28	388 ± 61	1923 ± 215
All Players	354 ± 87	384 ± 90	376 ± 97	400 ± 123	386 ± 101	1924 ± 464
Number of shifts						
Defence	8.5 ± 2.3 [b]	7.0 ± 1.9	6.7 ± 2.9 [b]	8.3 ± 3.4	7.3 ± 2.3	39.0 ± 12.1
Forwards	8.2 ± 1.8	7.9 ± 1.2 [b]	8.1 ± 1.1 [b]	9.7 ± 0.7	7.8 ± 1.0 [b]	42.3 ± 4.1
All Players	8.3 ± 1.9	7.5 ± 1.5 [b]	7.5 ± 2.0 [b]	9.1 ± 2.2	7.6 ± 1.6 [b]	41.0 ± 8.0
Average shift length (sec)						
Defence	43.1 ± 6.1 [a]	53.1 ± 6.2	58.6 ± 7.1	47.9 ± 8.8	51.1 ± 5.8	48.6 ± 4.9
Forwards	41.5 ± 7.3	50.2 ± 12.4	46.3 ± 1.3 [p]	41.2 ± 3.2 [p]	49.8 ± 4.7 [b]	45.4 ± 2.5
All Players	42.1 ± 6.7 [a,c]	51.4 ± 10.2	51.2 ± 8.1 [b]	43.9 ± 6.7	50.3 ± 5.0	46.7 ± 3.8
Shots-on-net by all players						
Defence	2	2	3	2	2	11
Forwards	4	7	6	8	2	27
All Players	6	9	9	10	4	38
Bodychecks delivered by all players						
Defence	1	1	4	1	3	10
Forwards	14	3	6	8	3	34
All Players	15	4	10	9	6	44
Shots blocked by all players						
Defence	1	0	5	2	3	11
Forwards	1	2	2	1	5	11
All Players	2	2	7	3	8	22

Data are presented as mean ± SD or counts. Data presented as counts (not statistically analyzed) were shown for all 6 defence, 9 forwards, or 15 players. [a], represents a difference from period 3, [b], represents a difference from period 4, [c], represents a difference from period 5, and [p], represents a statistical difference between defence and forward within a specific period or the entire game ($p<0.05$).

period 4 vs periods 3 ($p=0.034$) and 5 ($p=0.003$) in the very slow speed zone. Forwards also skated significantly further [$F(4,32) = 4.109$, $p=0.008$, $\eta=0.339$] in the slow speed zone (11.0-13.9 km/hr) in period 4 vs 5 ($p=0.014$).

Positional differences included defence skating further than forwards in the very slow speed zone in period 1 ($p=0.036$, $d=0.985$), forwards skating further in the fast speed zone in period 2 ($p=0.041$, $d=1.019$), period 3 ($p=0.048$, $d=1.128$), and the entire game ($p=0.043$, $d=0.954$), and forwards skating further than defence in the very fast speed zone (21.0-24.0 km/hr) in periods 1 ($p=0.001$, $d=1.702$), 2 ($p=0.003$, $d=3.512$), 3 ($p=0.006$, $d=1.844$), 4 ($p=0.002$, $d4=2.041$), and 5 ($p<0.001$, $d=2.701$) and the entire game ($p<0.001$, $d=3.059$). Additionally, forwards skated further in the sprint speed zone (>24.0 km/hr) in periods 1 ($p<0.001$, $d=2.983$), 2 ($p=0.008$, $d=1.673$), 3 ($p=0.014$, $d=1.593$), 4 ($p=0.001$, $d=2.426$), and 5 ($p<0.001$, $d=2.915$) and the entire game ($p<0.001$, $d=3.491$) (Figure 2).

Peak skating speeds ranged from 29.55 to 34.64 km/hr during the game, with greater speeds for forwards in periods 1 ($p=0.016$, $d=0.023$), 2 ($p=0.046$, $d=0.965$), 3 ($p=0.037$, $d=1.676$), and 4 ($p=0.030$, $d=1.239$) and the entire game ($p=0.028$, $d=1.118$) (Table 3). Peak acceleration (range of 3.87 to 4.95 m/s^2), peak deceleration (-7.49 to -5.37 m/s^2), number of accelerations (44 to 131), and number of decelerations (86 to 161) were not significantly different when comparing periods ($p>0.068$). However, peak deceleration was greater for forwards in period 1 ($p=0.019$, $d=1.531$), period 2 ($p=0.030$, $d=1.177$) and the entire game ($p=0.037$, $d=1.201$), and forwards had more decelerations in period 4 ($p=0.032$, $d=1.028$), when compared to defence.

As shown in Table 3, there were no consistent differences in sharp turns, wide turns, skating transitions, direction changes, and impacts when comparing periods, apart from differences in sharp turns for defence [$F(4,20) = 6.323$, $p=0.002$, $\eta=0.558$], forwards [$F(4,20) = 2.731$, $p=0.046$, $\eta=0.255$], and all players [$F(4,56) = 5.013$, $p=0.002$, $\eta=2.64$]. Defence had significantly more sharp turns in period 2 vs 4 ($p=0.021$), and forwards ($p=0.037$) and all players ($p=0.001$) had significantly more sharp turns in period 1 vs 5. Positional differences included more sharp turns for defence in period 2 ($p=0.011$, $d=1.546$), more wide turns for forwards in periods 3 ($p=0.018$, $d=1.429$), 4 ($p=0.005$, $d=1.676$), and 5 ($p=0.026$, $d=1.181$) and the entire game ($p=0.021$, $d=1.424$), and more skating transitions for defence in periods 1 ($p=0.020$, $d=1.376$), 2 ($p=0.006$, $d=1.704$), 4 ($p=0.047$, $d=0.919$), and the entire game ($p=0.020$, $d=1.298$). There were no significant differences in the changes of direction or impacts

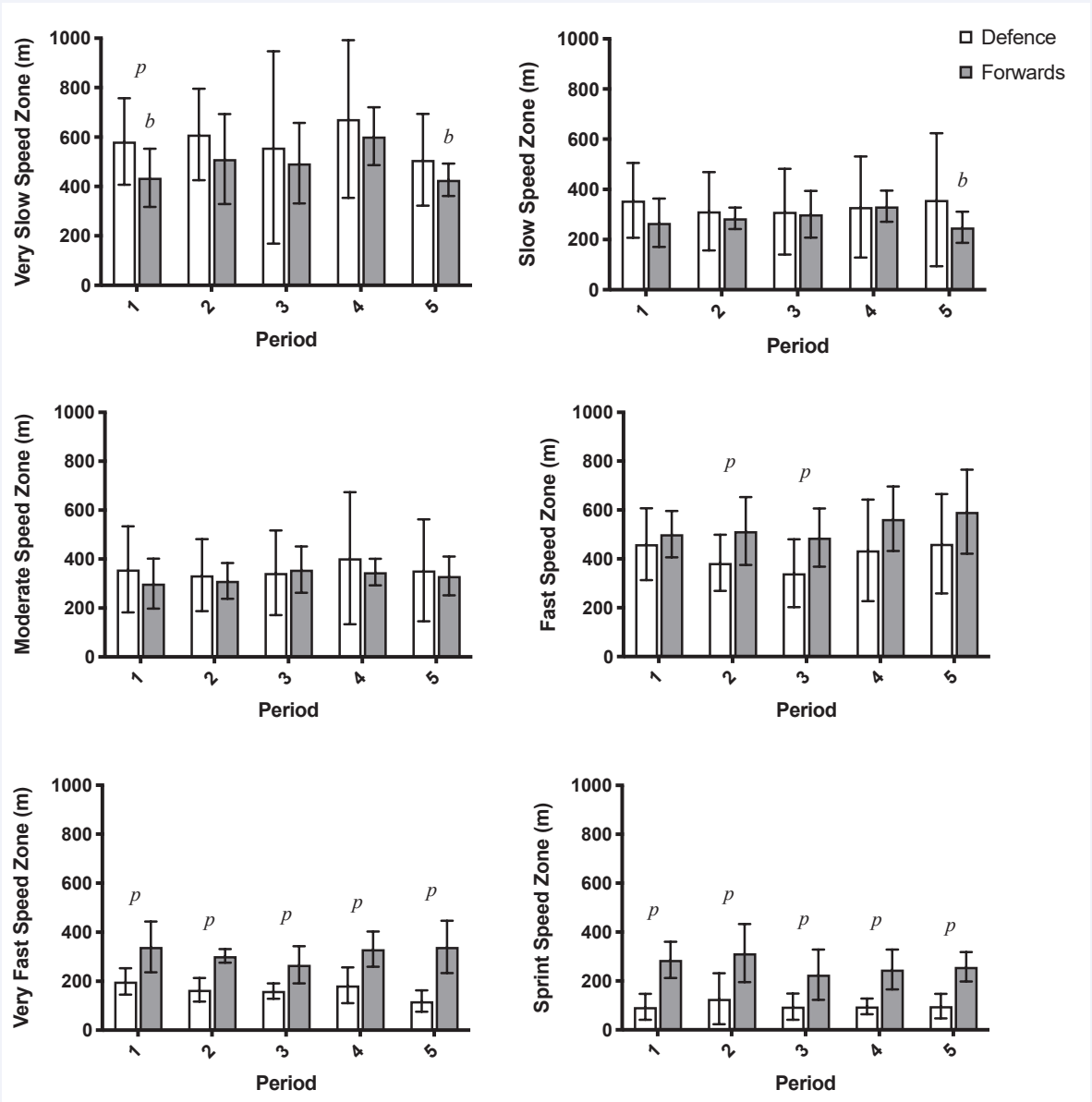

Figure 2 Mean skating distance travelled in a) very slow (1.0-10.9 km/hr), b) slow (11.0-13.9 km/hr), c) moderate (14.0-16.9 km/hr), d) fast (17.0-20.9 km/hr), e) very fast (21.0-24.0), and f) sprint (>24.0 km/hr) speed zones across periods in defence and forwards. Data are presented as mean ± SD. ^{b}, represents a difference from period 4, and ^{p}, represents a statistical difference between defence and forwards within a specific period ($p<0.05$).

between periods ($p>0.073$) or positions ($p>0.249$).

Internal load

Average TRIMP was 38.47 ± 14.83, 32.67 ± 15.39, 33.43 ± 19.18, 36.39 ± 18.29, 31.41 ± 11.89, and 174.30 ± 74.40 AU for periods 1-5 and the entire game, respectively. Player TRIMP ranged from 5.28 to 80.91 AU in a single period and 38.34 to 335.13 AU for the entire game. There were no differences in TRIMP for defence [$F(4,20) = 1.126$, $p=0.372$, $\eta=0.184$], forwards [$F(4,32) = 1.296$, $p=0.292$, $\eta=0.139$], or all players [$F(4,56) = 2.071$, $p=0.097$, $\eta=0.129$] when comparing periods. Forwards had significantly greater TRIMP than defence in period 2 ($p=0.026$, $d=1.369$), period 5 ($p=0.040$, $d=0.983$), and the entire game ($p=0.048$, $d=0.956$) (Figure 3).

This study quantified and compared player statistics, novel LPS external load metrics, and internal load (TRIMP) during the unique environment of a male varsity ice hockey championship (overtime) game across three periods of regulation time (60 min) and two additional periods of overtime (40 min) within positions and for all players. Main findings included that; i) the average skating distance for all players was 6248 ± 1500 m in the first three periods and maintained at 4408 ± 1143 in the two overtime periods, ii) both LPS metrics (external load) and TRIMP (internal load) indicated that workload was maintained throughout the entire 5 periods of the game by defence and forwards, and iii) forwards had greater peak skating speed, skated further in high-intensity speed zones (>21 km/hr), and had greater TRIMP than defence in most periods and the entire game.

Table 3: Local positioning system measured external load metrics across periods and positions.

	Period 1	Period 2	Period 3	Period 4	Period 5	Game Total
Peak speed (km/hr)						
Defence	28.75 ± 1.99	29.86 ± 1.53	29.19 ± 0.71	28.63 ± 2.12	29.40 ± 2.83	31.54 ± 1.10
Forwards	31.25 ± 1.51 [p]	31.39 ± 1.64 [p]	31.66 ± 1.96 [p]	30.91 ± 1.51 [p]	31.02 ± 1.45	32.88 ± 1.29 [p]
Total	30.25 ± 2.08	30.78 ± 1.72	30.67 ± 2.20	29.99 ± 2.06	30.37 ± 2.18	32.35 ± 1.36
Peak acceleration (m/s^2)						
Defence	3.76 ± 0.32	3.77 ± 0.40	3.73 ± 0.20	3.74 ± 0.59	3.81 ± 0.54	4.14 ± 0.34
Forwards	3.91 ± 0.50	3.99 ± 0.40	3.78 ± 0.37	4.10 ± 0.51	3.69 ± 0.43	4.30 ± 0.35
All Players	3.85 ± 0.43	3.90 ± 0.40	3.76 ± 0.31	3.96 ± 0.55	3.74 ± 0.46	4.23 ± 0.34
Number of accelerations (>2 m/s^2)						
Defence	19.2 ± 7.1	16.2 ± 5.8	15.5 ± 7.4	14.2 ± 5.7	14.0 ± 7.4	79.7 ± 24.2
Forwards	16.4 ± 4.3	19.4 ± 6.3	16.1 ± 6.4	19.1 ± 5.6	16.2 ± 6.1	89.0 ± 24.0
All Players	17.5 ± 5.5	18.1 ± 6.1	15.9 ± 6.6	17.1 ± 6.0	15.3 ± 6.5	85.3 ± 23.7
Peak deceleration (m/s^2)						
Defence	-5.17 ± 0.36	-4.84 ± 0.48	-5.15 ± 0.92	-4.99 ± 0.65	-5.27 ± 1.25	-6.13 ± 0.52
Forwards	-6.13 ± 0.81 [p]	-5.56 ± 0.72 [p]	-5.77 ± 0.63	-5.78 ± 0.93	-5.36 ± 0.82	-6.72 ± 0.46 [p]
All Players	-5.74 ± 0.81	-5.33 ± 0.74	-5.52 ± 0.79	-5.46 ± 0.90	-5.32 ± 0.97	-6.49 ± 0.55
Number of Decelerations (>2 m/s^2)						
Defence	26.5 ± 6.8	21.8 ± 4.0	22.0 ± 3.7	15.3 ± 8.4	18.5 ± 9.6	105.7 ± 17.5
Forwards	23.1 ± 6.2	25.7 ± 8.9	22.8 ± 4.1	22.6 ± 5.5 [p]	21.3 ± 5.0	117.0 ± 23.4
All Players	24.5 ± 6.4	24.1 ± 7.4	22.5 ± 3.8	19.7 ± 7.4	20.2 ± 7.0	112.5 ± 21.3
Number of sharp turns						
Defence	4.5 ± 1.8	3.8 ± 1.2 [b]	2.3 ± 2.3	1.3 ± 1.6	1.5 ± 1.8	13.8 ± 6.1
Forwards	3.4 ± 1.9 [c]	1.7 ± 1.5 [p]	3.0 ± 2.7	2.3 ± 1.7	1.0 ± 1.3	11.7 ± 4.9
All Players	3.9 ± 1.8 [c]	2.5 ± 1.7	2.7 ± 2.5	1.9 ± 1.7	1.2 ± 1.5	12.5 ± 5.4
Number of wide turns						
Defence	21.2 ± 5.8	18.7 ± 7.8	13.8 ± 7.3	15.7 ± 10.2	14.8 ± 8.7	84.7 ± 34.5
Forwards	26.1 ± 8.1	25.0 ± 8.9	24.3 ± 7.4 [p]	30.1 ± 6.6 [p]	28.0 ± 13.2 [p]	136.6 ± 38.3 [p]
All Players	24.1 ± 7.4	22.5 ± 8.8	20.1 ± 8.9	24.3 ± 10.8	22.7 ± 13.1	116.2 ± 43.9
Number skating transitions						
Defence	33.7 ± 10.7	30.7 ± 8.3	35.5 ± 19.8	32.7 ± 15.9	22.3 ± 11.6	157.3 ± 58.0
Forwards	20.1 ± 9.0 [p]	18.0 ± 6.5 [p]	20.7 ± 8.0	20.6 ± 9.7 [p]	17.0 ± 5.8	97.3 ± 30.2 [p]
All Players	25.4 ± 13.5	23.1 ± 9.5	26.6 ± 17.7	25.4 ± 13.5	19.1 ± 8.6	121.3 ± 51.5
Number of direction changes						
Defence	5.8 ± 2.9	6.1 ± 2.6	4.8 ± 2.1	4.7 ± 2.3	5.0 ± 3.8	26.7 ± 10.5
Forwards	5.0 ± 2.4	3.9 ± 2.9	5.6 ± 1.9	5.1 ± 3.1	3.7 ± 2.4	23.7 ± 7.8
All Players	5.3 ± 2.6	4.8 ± 2.9	5.3 ± 1.9	4.9 ± 2.7	4.2 ± 3.0	24.9 ± 8.7
Number of impacts						
Defence	1.5 ± 1.0	0.5 ± 0.5	1.5 ± 1.9	1.0 ± 1.3	1.0 ± 1.1	5.5 ± 2.7
Forwards	2.0 ± 1.8	1.0 ± 1.0	1.9 ± 1.6	1.6 ± 2.1	1.9 ± 1.4	8.6 ± 5.1
All Players	1.8 ± 1.5	0.8 ± 0.9	1.7 ± 1.7	1.3 ± 1.8	1.5 ± 1.3	7.3 ± 4.5

Data are presented as mean ± SD. [b], represents a difference from period 4, [c], represents a difference from period 5, and [p], represents a statistical difference between defence and forward within a specific period or the entire game ($p<0.05$).

Total skating distance and skating distance in speed zones

Given the unique situation of a championship game that lasted 5 full periods of ice hockey (100 min), differences between periods because of potential coaching adjustments, specific game situations, or player fatigue, could be expected. LPS metrics in this study revealed that skating distance was maintained in the first three periods and in periods 4 and 5 in both defence and forwards. The average skating distance in the first three periods was 6248 ± 1500 m, which was comparable to another study that reported that elite junior Danish U20 players skated ~6 km during a simulated ice hockey game [3]. Other studies reported average skating distances of ~4 and 3.7 km during 5 international games for defence and forwards of elite junior U20 Canadian players and ~4.6 km in an NHL game [22,29]. Differences in skating distances could potentially be the result of some players not participating in regular shifts or having the exact TOI between when comparing competitive games. Regardless, this outlines the importance of considering a wide range of player workloads that would be encompassed in team sport.

Based on speed thresholds previously outlined in ice hockey [29], 45% of skating was in the high-intensity skating zones (>17 km/hr) in the present study. This was slightly less than the ~50% of skating in the top three high-intensity skating zones (>17 km/hr) reported in two other ice hockey studies in elite-level junior players [3,22]. Our results were more comparable with those reported in an in-season NHL game (~44% skating was considered high-intensity) determined by a portable multiple-camera computerized tracking system [29]. Skating distance in different speed zones provides a valuable external load measure given the differences in workload intensity when skating the same distance in a slow vs. fast speed zone. Including a measure of intensity in skating distance can provide an estimate of how hard a player is working, similar to internal load measures that consider heart rate zones and TRIMP. Future research should consider using peak practice or game speed to determine individualized thresholds, given that rugby research has reported that individualized speed thresholds may be more appropriate when measuring external load [34,35].

Period differences

Previous ice hockey research reported higher external loads in the first period compared to the third period when using video analysis [29], accelerometry [19,20], and LPS [3,22]. However, internal load was reported as higher in period 3 vs 1 in regular season games for both female and male varsity ice hockey players [14]. These results suggest that players may not be able to maintain external load throughout an entire game and player's internal load may increase later in games to sustain their external workload. Contrary to the hypothesis that player workload would decrease as the game went on, there were no major changes in LPS external load or TRIMP internal load measures across periods. Only small differences between periods were identified for turns and skating distance in very slow and slow speed zones.

Sprint skating speeds were reportedly lower in period 3 and 4 (overtime) vs period 1 and 2 in NHL players [29]. PlayerLoad (only defence), skating load, explosive efforts, and explosive ratio (defence and forwards) all had moderate differences across periods in elite female ice hockey players, with decreased averages from period 1 to period 3 [20]. Relative load was greater in the first period and relative intensity was lower in the third period in AHL players [19]. Lastly, there were fewer accelerations and decelerations in the second and third periods in elite junior Danish U20 male players [3], and less skating in very fast (only defence) and sprint speed zones (defence and forwards) in period 3 vs 1 in elite junior Canadian U20 male players [22].

Given the game's high intensity, length, and championship implications, it would have been reasonable to speculate that workload decreases may occur later in the game due to fatigue. However, this was also a season-deciding game, where players were maximizing effort with their season on the line. Players participated in daily practices and weekly games throughout the season, which allowed for an apparent high fitness level that allowed them to maintain their workload throughout the game. Additionally, players were provided with water, sports drink, and carbohydrate rich snacks throughout the periods and intermissions to fuel, maintain performance and ideally limit fatigue throughout the extended game.

Positional differences

As previously mentioned, most differences in LPS and TRIMP measures occurred between positions. Forwards not only had significantly higher peak speeds in 4 of 5 periods and the entire game, but they also skated further at higher speeds, when compared to defence. Internal load TRIMP measures were also consistently greater in forwards compared to defence, however, these differences only reached statistical significance in periods 2 and 5, and the entire game. Several other studies have also reported similar positional differences (defence vs forwards).

Douglas et al. [21], reported that forwards had greater PlayerLoad, TRIMP, and explosive efforts in both training and competition for world-class women's ice hockey. Forwards also had more skating at high-intensity speeds during elite junior male ice hockey and NHL games [3,29]. AHL forwards also had more high-intensity external load during games [19]. Although, defence spent more time on the ice (47%), had greater total skating distance (29%) [29], and trained at a higher relative intensity [19]. While many LPS metrics in Table 2 did not reach significance, several averages appeared to be trending higher in forwards than defence. Lastly, defence had more skating transitions than forwards, which may be expected given their need for pivoting from forwards-to-backwards skating or vice versa during their game play. This information outlines the importance of adapting and targeting position-specific training methods to ensure that players can optimize performance when needed.

CONCLUSION

This was the first study to objectively measure the external load of male varsity ice hockey players using wearable LPS technology in the unique setting of a championship overtime game lasting 5 full periods (100 min). It was determined that players had extremely high external load, given the mean skating distance was 6248 ± 1500 m in the first three periods and 4408 ± 1143 in the last 2 periods of the game. The maintenance of

external (LPS) and internal (TRIMP) loads in the latter periods outlined that players were able to maintain their workload throughout the extended game. The main positional differences revealed that forwards had higher peak speed in most periods and the entire game. Forwards also skated further at higher speeds (>24 km/hr) and had greater TRIMP throughout the game when compared to defence. The ability for the players to maintain effort and intensity during this extended overtime game was impressive, and suggests that their preparation, training, and nutritional fueling contributed to the maintenance of these high external loads. Additionally, this suggests that players are able to maintain their workload to a greater extent when a successful outcome of the competition is imperative. Most importantly, this information provides novel information to players, coaches, and researchers regarding the workload of ice hockey players during a game, while also providing results for comparison with the limited number of other studies available in this area.

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