Analysis of High-Intensity Skating in Top-Class Ice Hockey Match-Play in Relation to Training Status and Muscle Damage

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Abstract

Lignell, E, Fransson, D, Krustrup, P, and Mohr, M. Analysis of high-intensity skating in top-class ice hockey match-play in relation to training status and muscle damage. *J Strength Cond Res* 32(5): 1303–1310, 2018—We examined high-intensity activities in a top-class ice-hockey game and the effect of training status. Male ice-hockey players ($n = 36$) from the National Hockey League participated. Match analysis was performed during a game and physical capacity was assessed by a submaximal Yo-Yo Intermittent Recovery Ice-hockey test, level 1 (YYIR1-IH_{SUB}). Venous blood samples were collected 24-hour post-game to determine markers of muscle damage. Players performed 119 ± 8 and 31 ± 3 $m \cdot min^{-1}$ of high intensity and sprint skating, respectively, during a game. Total distance covered was 4,606 ± 219 m (2,260–6,749 m), of which high-intensity distance was 2042 ± 97 m (757–3,026 m). Sprint-skating speed was 5–8% higher ($p \leq 0.05$) in periods 1 and 2 vs. period 3 and overtime. Defensemen (D) covered 29% more ($p \leq 0.05$) skating in total than forwards (F) and were on the ice 47% longer. However, F performed 54% more ($p \leq 0.05$) high-intensity skating per minute than defensemen. Plasma creatine kinase (CK) was 338 ± 45 (78–757) $U \cdot L^{-1}$ 24-hour post-game. Heart rate loading during YYIR1-IH_{SUB} correlated inversely ($p \leq 0.05$) to the frequency of high-intensity skating bouts ($r = -0.55$) and $\dot{V}O_2max$ ($r = -0.85$) and positively to post-game CK ($r = 0.49$; $p \leq 0.05$). In conclusion, ice hockey is a multiple-sprint sport that provokes fatigue in the latter half of a game. Forwards perform more intense skating than defensemen. Moreover, high-intensity game activities during top-class ice hockey are correlated with cardiovascular loading during a submaximal skating test. Taken together, training of elite ice-hockey players should improve the ability for repeated high-intensity skating, and testing should include the YYIR1-IH_{SUB} test as an indicator for ice-hockey–specific physical match performance.

Key Words match analysis, elite athletes, performance, fitness testing, team sports, intermittent exercise

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Introduction

Ice hockey is a major international sport with a total of 1,808,879 registered players in the International Ice Hockey Federation's 74 member countries (15). It is described as a fast-paced contact sport with an activity pattern characterized by intermittent high-intensity bouts of skating demanding explosive accelerations and changes in speed and direction (10,12,14,30). Moreover, the game includes high-impact body contact and execution of a variety of skilled technical tasks. Compared with other team sports, ice-hockey players usually are on the ice for approximately 20–35 30–90 second long shifts separated by recovery periods, corresponding to a total playing time of 15–25 minutes for individual players (37). Thus, the sport differs from most other team sports, which is likely to impact the physical game demands. However, to date there are limited scientific information on physical aspects associated with ice-hockey match-play.

In other team sports, such as soccer, rugby, team handball, and basketball, the literature has greatly expanded during the last decade, describing game demands and fatigue patterns in detail by applying match analysis with technology using high sampling rates (15–100 Hz) (8,13). For example, fatigue has been observed to develop throughout a soccer (26), team handball (35), and Ultimate Frisbee (16) game. However, in contrast to other team sports for these types of studies are sparse in ice-hockey. Recently, an on-ice repeated shift test was conducted to evaluate the susceptibility of ice-hockey players to fatigue during high-intensity skating (33). However, a characterization of high-intensity activities and

Table 1. Subject characteristics.*

Age (yrs)	Height (cm)	Body mass (kg)	Body fat (%)	$\dot{V}O_2max$ ($ml \cdot min^{-1} \cdot kg^{-1}$)	BL_{peak} ($mmol \cdot L^{-1}$)	CMJ_{peak} (cm)
28 ± 1	185 ± 3	79 ± 3	10.3 ± 0.3	58.8 ± 0.9	15.3 ± 0.2	44 ± 1

*Age, body composition, maximal oxygen uptake, peak blood lactate (BL_{peak}), and peak countermovement jump (CMJ_{peak}) performance of top-class ice-hockey players ($n = 18$).

game-induced fatigue patterns during official top-class competitive games are completely missing and are highly warranted by sports scientists and coaches.

Several studies of physical capacity of ice-hockey players have been conducted and are demonstrating that professional players have high anaerobic and aerobic capacities, as well as great muscle strength (29,34,37), which is similar to athletes in soccer, rugby, team handball, and basketball. Thus, in general ice-hockey players display some of the same basic physiological characteristics as other team-sport athletes. However, the vast majority of the testing protocols applied to elite ice-hockey players are conventional laboratory tests, which may have limited relevance for competitive performance on the ice (5). Moreover, these types of tests have low practical value because of being time-consuming and requiring expensive equipment. In professional ice hockey, the game frequency is high, which render a field-test approach, where players can be assessed within a training session. In other team sports, strong relationships have been reported between high-intensity activities in games and specifically designed field tests (5). In ice-hockey, tests conducted on the ice may be even more important because of the specific movements of skating. In support of this notion, specific physical fitness tests performed on the ice have been shown to be of great importance in the selection process for elite ice-hockey players, because players selected for the team display better test scores than players who are rejected (37). These finding are further supported by recent observations by Peterson et al. (33), but it is currently unknown whether these types of tests predict actual game performance, which is an essential step for proper validation of a sports-specific fitness testing protocol.

In addition to the limited data on match activities and on-ice performance of competitive ice-hockey players, most of the studies in scientific literature on ice-hockey are conducted at a subelite standard such as college players (34). Because the level of play has a major impact on the match performance of team-sport athletes (25), results from top-class ice-hockey athletes are highly warranted.

Thus, the purpose of the present study was to examine high-intensity activity and fatigue patterns during a competitive male top-class ice-hockey game, and to determine the effect of training status on on-ice performance and game-induced muscle damage. We hypothesize that most of the skating performed in top-class ice-hockey games is performed at high intensities, that players may experience fatigue in games, and that forwards (F) display more intense activity profiles than defensemen (D). Finally, we are testing the hypothesis that high-intensity intermittent on-ice exercise capacity is associated with game performance.

Methods

Experimental Approach to the Problem

To investigate high-intensity activity during a competitive male top-class ice-hockey game, the present study applies a within-subject design. Match analysis were performed during an official competitive top-class ice-hockey game where game activity data were collected using a portable multiple-camera computerized tracking system (Amisco Pro, version 1.0.2, Nice, France; Mohr et al.) (27). Moreover, to determine the effect of training status on on-ice performance, the players also performed fitness tests in the laboratory as well as a submaximal version of the Yo-Yo Intermittent Recovery test, level 1 (2) on the ice, dubbed the submaximal Yo-Yo Intermittent Recovery Ice-Hockey test, level 1 (Yo-Yo IR-IH_{SUB}) to evaluate the relationship between match activities and training status. Finally, blood was drawn 24-hour post-game to assess markers of game-induced muscle damage and inflammation.

Subjects

Male professional ice-hockey players (age: 21–37 yrs; $n = 36$) from the National Hockey League (NHL) participated in the match analysis part of the study. The players represented all outfield positions. The sample included 11 D and 24 F, of whom 10 were lateral forwards (LFs) and 15 center forwards (CFs). The players had played 751 ± 49 (range: 245–1,455) games in the NHL and taken part in 11 ± 1 (6–19) NHL seasons. Several of the players were Olympic gold-medal winners ($n = 7$), world champions ($n = 7$), World Cup winners ($n = 1$), and winners of the Stanley Cup ($n = 14$). Eighteen of the players were also tested for physical capacity and had a resting blood sample taken (Table 1). This subgroup also represented all outfield positions (D, $n = 6$; F, $n = 12$ [LF, $n = 7$; CF, $n = 5$]). Written informed consent was obtained from the players before the study, and the study conformed to the code of ethics of the Declaration of Helsinki and adhered to the human subject guidelines of the University of Gothenburg, Sweden. The study was approved by the Ethical Commitee at the University of Gothenburg, Sweden.

Table 2. Game distances during an ice-hockey game in meters.*

Total skating distance (>1 km·h^{-1})	4,606 ± 219
Very slow speed skating (1.0–10.9 km·h^{-1})	1,405 ± 87
Slow speed skating (11.0–13.9 km·h^{-1})	512 ± 35
Moderate speed skating (14.0–16.9 km·h^{-1})	648 ± 43
Fast speed skating (17.0–20.9 km·h^{-1})	1,011 ± 53
Very fast speed skating (21.0–24.0 km·h^{-1})	547 ± 32
Sprint skating (>24.0 km·h^{-1})	484 ± 34

*Distance covered in meters at different speed thresholds during a competitive top-class ice-hockey game ($n = 36$). Data are means ± SEM.

Procedures

Match analysis data were collected during an official NHL-game played at 07.00 PM in the middle of the competitive season using a multiple-camera computerized tracking system (Amisco Pro, version 1.0.2; Mohr et al. (27) Player movements were captured during the match by cameras positioned at roof level in the ice rink and analyzed using proprietary software to produce a data set on each player's match activities as previously described (11). The validity of the multiple-camera system (MCS) was quantified to verify the capture process and data accuracy (8,11), as well as in relation to intensity variations in a game (36). This type of player activity profiles have been assessed previously in other team sports using the same multiple-camera semi-automatic passive tracking system (6,11,27,36). Data for skating profile (speed, distance, and duration) at the predefined speed thresholds (see below) were determined for each player. Data are expressed both as total distances and distances per time on ice, taking into account differences in time on ice.

The Amisco system is a multiple-camera match analysis system (Amisco Pro, version 1.0.2). The movements of all outfield ice-hockey players were observed during the game by 8 stable, synchronized cameras positioned at the top of the stadium at a sampling frequency of 25 Hz. Signals and angles obtained by the encoders were sequentially converted into digital data and recorded on 6 computers for post-match analysis. From the stored data, distance covered, time spent in the different movement categories and frequency of occurrence for each activity were determined by Athletic Mode Amisco Pro (6,11,27,36). The locomotor categories were chosen after pilot testing of skating speeds in an ice-hockey game. Skating distances were coded into the following categories and speed thresholds: very slow skating (1–10.9 km·h^{-1}), slow skating (11–13.9 km·h^{-1}), moderate-speed skating (14–16.9 km·h^{-1}), fast skating (17–20.9 km·h^{-1}), very fast skating (21–24 km·h^{-1}), and sprint skating (>24 km·h^{-1}). Similar speeds for each category have been employed previously in other team sports (27,28). Total distance represented the sum of distances in all categories, whereas high-intensity skating represented the sum of fast, very fast and sprint skating or skating faster than 17 km·h^{-1}. The MCS approach has been shown to be a precise method for assessing football game activities (8,11) and is sensitive at detecting work-rate changes during a game (36).

A 6-minute submaximal version of the Yo-Yo Intermittent Recovery test, level 1 (Yo-Yo IR1) with heart rate measurements (Team System 2, Polar Electro, Kempele, Finland), as previously described (17,18), was performed on the ice (Yo-Yo Intermittent Recovery Ice-hockey test, level 1 submaximal test; YYIR1-IH$_{SUB}$), in the official ice rink (stadion) of the team. The test was performed on the ice rink ($n = 18$) at the stadium at 11.00 AM as the first part of a training session. The test was performed 4 days after a game and the players prepared for the test following standardized pretraining procedures. The test consisted of 2 × 20-m shuttle skates with gradual speed increments signalled by audio beeps (5). Between each shuttle skating bout, the participants had a 10-second recovery period comprising 2 × 5 m of slow skating. The test was terminated after 6 minutes and the heart rate was determined using Polar Vantage NV heart rate monitors (Polar, Electro Oy, Kempele, and Finland). The chest monitor and wrist receiver (weighing; 100 g), were placed on the player approximately 30 minutes before the test, as previously described (18). The test result was the heart rate after 6 minutes expressed as a percentage of maximum heart rate. Before the test, the subjects performed a standardized warm-up, as described by Bangsbo and Mohr (5). Moreover, the players were familiarized with the testing procedure 1 week ahead of the test as suggested (5). The Yo-Yo IR1 test has been shown to have a test–retest coefficient of variation of 5% (2). Maximal oxygen consumption ($\dot{V}O_2max$) was determined for each subject ($n = 18$) by means of an incremental cycling test to volitional exhaustion (35) on an electronically braked cycle ergometer (Monark Ergomedic 839 E; Monark AB, Varberg, Sweden). The test was initiated at 200 W and increased by 25 W every minute until the subjects could no longer complete the given load. Pulmonary oxygen uptake was continuously measured throughout the test using an automated online gas analysis system (model CPX/D; Medgraphics, St Paul, MN, USA). The test was performed 2 weeks before experimental game. All players were familiarized with the testing procedure. Maximal heart rate (HRmax) was assessed during the test using Polar Vantage NV heart rate monitors (Polar, Electro Oy, Kempele, Finland). Blood lactate concentration was analyzed (Lactate Pro, Arkray, KDK, Kyoto, Japan) using a hand-held portable analyzer from a 5 μL sample taken from the index fingertip 2 minutes after the point of fatigue in the bicycle test. In addition, a repeated countermovement jump test consisting of 5 maximal vertical jumps interspersed by 5-second recovery was performed (n = 18). The jumps were performed with the hands fixed on the hips and was performed on a jumping mat (Time It; Eleiko Sport, Chicago, IL) at 1 PM on a training day after a standardized warm-up in accordance with Mohr and Krustrup (24). All players were familiarized with the repeated jump test on a previous occasion.

A resting venous blood sample was obtained from an arm vein using the venipuncture technique 24 hours after the game (n = 18). Plasma was obtained by centrifugation (at 1370 g, 4° C, 10 minutes) after collecting a blood portion in tubes containing EDTA or SST gel/clot activator, respectively, creatine kinase (CK), white blood cell (WBC), C-reactive protein (CRP), testosterone, and cortisol, as previously described (23).

Statistical Analyses

Data are mean ± standard error of the mean (SE), unless otherwise stated. Differences in distance covered per minute in the different game periods were analyzed using a 1-way analysis of variance (ANOVA) with repeated measurements. Differences in game activity pattern variables between playing positions were analyzed by a 2-way ANOVA test. Correlation coefficients were determined between high-intensity game variables, training status and markers of muscle damage and tested for significance using the Pearson's regression test. Statistical significance was set at $p \leq 0.05$.

Results

Skating Distances

Total time on the ice was 17.3 ± 1.1 minutes (9.5–25.5 minutes). Total time on ice in the experimental game correlated with average time on ice during the season (16.5 ± 0.9 minutes) with a CV of 1.7%. Total distance covered during a game was 4,606 ± 219 m (2,260–6,749 m), of which 31, 11, and 14% was covered as very slow speed, slow speed, and moderate speed skating (Table 2). The players covered 2,042 ± 97 m (757–3,026 m) in high-intensity skating, of which 49, 27, and 24% was covered as fast, very fast, and sprint skating (Table 2). The players covered 119 ± 8 (54–164) and 31 ± 3 (6–56) $m \cdot min^{-1}$ during the game at high-intensity skating and sprint skating, respectively. Figure 1 shows the individual variations in total skating distance and high-intensity skating distance.

High-Intensity Match Profile

The players performed 19 ± 1 (8–32) sprints during the game with an average length of 26 ± 1 (17–34) m. Peak and average sprint speeds were 28.6 ± 0.1 and 25.5 ± 0.1 $km \cdot h^{-1}$. The players performed 33 ± 3 (15–58) and 61 ± 4 (34–85) skating bouts at very fast and fast speed, resulting in 113 ± 7 high-intensity bouts in total, corresponding to 7 ± 0 (4–10) $bout \cdot min^{-1}$. The average length of the very fast and fast skating bouts was 16 ± 0 and 15 ± 0 m, respectively.

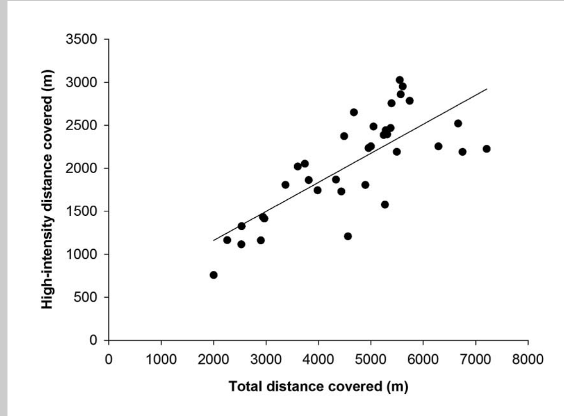

Figure 1. Interindividual (n = 36) relationship in relation to high-intensity skating distance and total skating distance during a competitive top-class ice-hockey game.

During the 3 playing periods, the players covered 139 ± 11, 166 ± 12 and 146 ± 14 m, respectively, of sprint skating with no differences between periods. The players covered

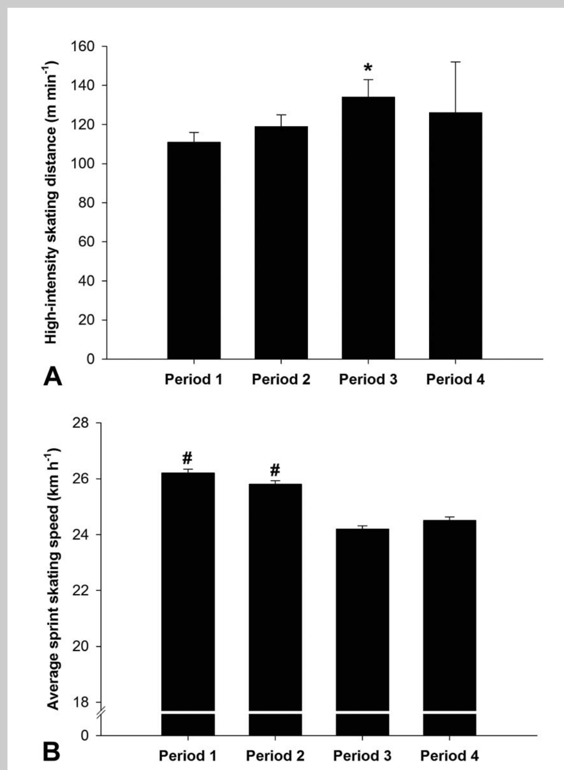

Figure 2. High-intensity skating distance per minute (A) and average sprint-skating speed (B) during periods 1, 2, 3, and 4 (overtime) in a competitive top-class ice-hockey game (n = 36). Data are means ± SE. *Significant difference from periods 1 and 2. # Significant difference from periods 3 and 4. Significance level $p \leq 0.05$.

63 ± 8 m in the overtime period. Moreover, the players completed 586 ± 28, 621 ± 30 and 717 ± 48 m of high-intensity skating during the 3 periods, respectively, with longer ($p \leq 0.05$) distances in period 3 than in periods 1 and 2. In the overtime period, the players completed 118 ± 17 m of high-speed skating. When expressed in relation to time on ice, the players performed 134 ± 9 $m \cdot min^{-1}$ of high-intensity skating in period 3, which was more ($p \leq 0.05$) than in period 1 and tended ($p = 0.07$) to be longer than in period 2 ($p \leq 0.05$; Figure 2A). In the overtime period, the players completed 126 ± 26 $m \cdot min^{-1}$ of high-intensity skating (Figure 2A).

Average sprint speed was 26.2 ± 0.1 and 25.8 ± 0.1 $km \cdot h^{-1}$ in periods 1 and 2, which was higher than in period 3 and in the overtime period (24.2 ± 0.1 and 24.5 ± 0.1 $km \cdot h^{-1}$, respectively; Figure 2B). There was no difference in peak sprinting speed between periods.

Defensemen covered 29% more ($p \leq 0.05$) skating distance in total than F (5,445 ± 337 vs. 4,237 ± 248 m, respectively), but D had 47% longer ($p \leq 0.05$) time on ice than F (22.3 ± 1.6 vs. 15.2 ± 0.9 seconds, respectively), resulting in a higher average skating speed for F than for D (283 ± 7 vs. 247 ± 8 $m \cdot min^{-1}$, respectively). There was no difference in high-intensity skating between D and F (1938 ± 114 vs. 2087 ± 131, respectively), but F covered 54% more ($p \leq 0.05$) distance by high-intensity skating per time unit (139 ± 4 vs. 90 ± 6 $m \cdot min^{-1}$, respectively). Forwards covered 55 and 33% more ($p \leq 0.05$) distance in total by sprint and very fast skating in comparison to D (Figure 3). In contrast, D covered greater ($p \leq 0.05$) distances than F in total by fast, moderate, slow, and very slow skating (Figure 3). There was no difference in peak or mean sprint speed between F and D.

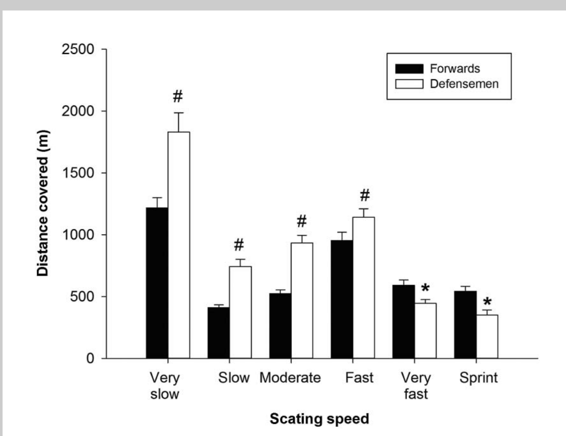

Figure 3. Total distance covered within different movement categories by forwards (black bars; $n = 25$) and defensemen (white bars; $n = 11$) during a competitive ice-hockey game. * Significant difference from defensemen. # Significant difference from forwards. Significance level $p \leq 0.05$.

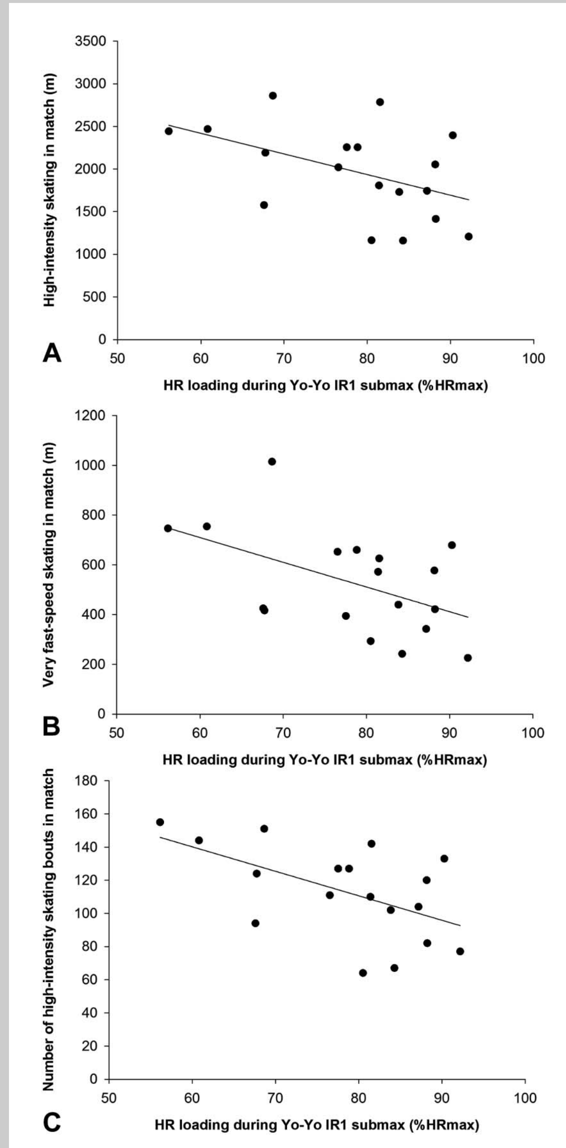

Figure 4. Interindividual relationship ($n = 18$) in relation to high-intensity skating distance (A), very fast speed skating distance (B), and number of high-intensity skating bouts (C) in a competitive ice-hockey game, and heart-rate loading ($\%HR_{max}$) during the YYIR1-IH_{SUB} test.

Post-Game Blood Profile

Plasma CK was 338 ± 45 $U \cdot L^{-1}$ (82–672) 24 hours after the game. Plasma WBC and CRP were 5.3 ± 0.4 (4.2–12.0) $k \times 10^3$ and 1.8 ± 0.7 $mg \cdot L^{-1}$ (0.3–10.7), respectively, whereas plasma testosterone and cortisol were 16 ± 1 (12–28) $nM \cdot L^{-1}$ and 548 ± 26 (419–779) $nM \cdot L^{-1}$, respectively, 24 hours post-game.

Physical Capacity

$\dot{V}O_2max$ was 58.8 ± 0.9 (54.0–67.6) $ml \cdot min^{-1} kg^{-1}$ and peak blood lactate was 15.3 ± 0.2 (13.4–16.6) $mmol \cdot l^{-1}$ (Table 1). Mean and peak jump performance in the 5-jump test was

42 ± 1 (32–55) and 44 ± 1 (35–57) cm (Table 1). HRmax determined during the bike test was 186 ± 2 (104–177 $b \cdot min^{-1}$). Cardiovascular loading in the 6-minute submaximal Yo-Yo IR1 skating test was 147 ± 5 $b \cdot min^{-1}$, corresponding to 78.9 ± 2.3 (56.1–92.2) % HRmax.

Correlations Between Match Variables, Physical Capacity, and Blood Profile

Cardiovascular loading during the submaximal Yo-Yo IR1 skating test correlated ($r = -0.47$, -0.50 and -0.55; $p \leq 0.05$) with total high-intensity, very fast speed skating distance, and number of high-intensity skating bouts, respectively (Figure 4). There was no correlation between total skating distance and physical capacity. However, $\dot{V}O_2max$ correlated with total high-intensity skating distance ($r = 0.54$; $p \leq 0.05$) and cardiovascular loading during the submaximal Yo-Yo IR1 skating test ($r = -0.85, p \leq 0.05$). Plasma CK and cardiovascular loading during the submaximal Yo-Yo IR1 skating test were correlated ($r = 0.49$; $p \leq 0.05$).

Discussion

The present study is the first to study high-intensity match activities in relation to training status in top-class ice-hockey players. The principal findings were: (a) top-level ice-hockey players cover nearly half the total distance in a game by high-intensity skating, of which one-fourth is performed as sprint skating; (b) the activity pattern is highly intermittent, with the players performing an average of 7 high-intensity skating bouts every minute, averaging 15 m; (c) distance covered by sprint skating is lower in the latter periods of a game than earlier in the game, which may indicate fatigue; (d) F perform much more high-intensity skating than D; and (e) cardiovascular loading during a submaximal Yo-Yo Intermittent Recovery skating test is inversely correlated with high-intensity performance in a game.

As far as the authors are aware, this is the first analysis of the high-intensity exercise profile of top-class ice-hockey players competing at the highest international standard. Players are on the ice for ~10–25 minutes and skate 2,300–6,800 m during a game, which is comparable to running distances in other sports of similar duration and with free substitutions, such as team handball (35), ultimate frisbee (16), and basketball (38). However, in accordance without hypothesis, high-intensity skating (>17 $km \cdot h^{-1}$) accounts for ~45% of total skating distance or, on average, ~120 $m \cdot min^{-1}$, which is a markedly higher proportion of high-intensity activity than in any other team sports. Ice hockey is played on ice, which is likely to play a role when defining high-intensity activity; however, sprinting comprises 11% of the total distance covered and one-fourth of the high-intensity skating, which also is higher than in other team sports (16,35,38). Moreover, the frequency of high-intensity skating bouts is also greater (7 $bouts \cdot min^{-1}$) compared with other team sports. Thus, top-class ice hockey is a high-intensity intermittent or multiple-sprint sport placing extraordinarily high demands on the ability to perform short, explosive, high-intensity bouts, and to the ability to recover after repeated intense exercise.

The present findings reveal significant correlations between cardiovascular loading during the YYIR1-IH_{SUB} test and total high-intensity skating (>17 $km \cdot h^{-1}$) distance, very fast skating (>21 $km \cdot h^{-1}$) and frequency of high-intensity skating bouts (Figure 4), which verifies our hypothesis. In fact, cardiovascular loading during the intermittent skating test explained 22–30% of the variance in these high-intensity game activities. The YYIR1 test has previously been shown to predict high-intensity running in soccer (17,27), basketball (31), team handball (40), and Ultimate Frisbee (16) games. Moreover, heart-rate loading during the submaximal version of the test correlated with match performance in other team sports (18,27). In the present study, YYIR1-IH_{SUB} performance correlated largely ($r = 0.85$) with $\dot{V}O_2max$, indicating the strong aerobic component of the test. Thus, the YYIR1-IH_{SUB} test used in the present study provides direct validity for high-intensity efforts in a competitive game and seems to be a useful tool for evaluating a player's ice hockey specific aerobic capacity. In support of this, Peterson et al. (33) report a correlation between aerobic capacity and repeated shift performance in ice-hockey players using a simulated model. These inter-individual relationships also indicate that aerobic capacity is a highly important performance variable in multiple-sprint sports such as ice hockey, despite the very intense and short exercise intervals of the game. This observation may be logical, because the ability to recover between the 4–10 high-intensity efforts per minute on ice, as well as between shifts, is suggested to be a key performance indicator in competitive ice hockey (20). Several studies have provided evidence of the importance of high aerobic capacity in multiple-sprint sports (1,20,22). Indeed, a recent study from our research group demonstrated that number of sprints and peak sprint speed in a soccer game correlated with acetyl-CoA carboxylase protein, explaining a third to fourth of the variance in these game parameters. In addition, there was a very large inverse correlation ($r = -0.87$) between acetyl-CoA carboxylase protein expression and the game-induced decrement in repeated sprint ability. Moreover, there are solid findings in the literature reporting an upregulation of muscle oxidative capacity after high-intensity intermittent training (9,32,39), indicating the importance of the aerobic energy system during repeated intense exercise. Thus, in multiple-sprint sports such as ice-hockey aerobic abilities, including muscle oxidative capacity, are likely to play an important role.

The present study is the first to address fatigue development during a competitive ice-hockey game at the highest competitive standard. Fatigue during competitive team-sport games has been studied in detail especially in soccer (3,26). A common approach in other team sports has been to compare work rates in different stages of a game to search for systematic indications of fatigue development (13). In the present study, high-intensity skating, when corrected for differences in time on ice, was significantly longer in period 3 than in period 1 and tended to be longer than in period 2 (Figure 2A). However, average sprint-skating speed was lower in period 3 and in the overtime period than in periods 1 and 2, which is supported by others using a simulated ice-hockey–specific protocol (33). Thus, although the players are performing more high-intensity skating in period 3, the quality of the sprinting seems to be impaired, indicating fatigue development during the latter half of an ice-hockey game, which is in accordance with our research hypothesis. A newly published study by Fransson et al. (13) showed that top-class soccer players tend to experience temporary fatigue after the most intense 1-minute periods of a game and that players appear to be physically impaired during the next 5 minutes. These peak-intensity periods in soccer may represent similar physiological demands as the 30–60 seconds shifts in an ice-hockey game. However, the recovery between shifts in an ice-hockey game is only 2–3 minutes long, which supports the relevance of the temporary fatigue concept in this sport. Peak periods in soccer have been shown to involve a high anaerobic energy turnover and concomitant muscle acidosis (19), which may affect the fatiguing process (21). Moreover, performance during peak periods in soccer is correlated with muscle variables associated with fatigue resistance during intense exercise (28). Indeed, the total concentration of Na^+-K^+ pumps explained ~50% of the variance in peak period performance in the study by Mohr et al. (28). Future research should aim at elucidating these relationships in the sport of ice hockey.

The plasma CK levels 24 hours after an ice hockey game reached ~350 $U \cdot L^{-1}$, 1–2-fold lower than observations 1 day after a soccer game (23). Thus, the degree of muscle damage seems to be lower in ice hockey and soccer, which may partly be associated with a lower number of impacts because of skating instead of running and the overall shorter exercise time in ice hockey. An interesting finding was the inverse relationship between plasma CK and cardiovascular loading during the submaximal YYIR1 ice-hockey test. Thus, the players with the highest fitness level seem to have the lowest degree of muscle damage, which indicates the importance of having a high training status to cope with multiple match-play in ice hockey. The blood markers of inflammation, immune response, and stress hormonal responses were all within a normal range and markedly lower than 24 hours after a soccer game, indicating that top-class ice-hockey players are physically only moderately affected 24 hours after a competitive game. Thus, unlike team sports with limited substitutions, ice hockey games may be played after only 1 or 2 days of recovery.

Large inter-player variations were observed within all movement categories, which is a common finding in other team sports (7,13,25,35). This can partly be explained by tactical role, because large differences were observed between D and F. Defensemen covered ~30% more distance than F, which is partly explained by nearly 50% longer time on ice and longer absolute skating distance within the slowest skating categories. On the other hand and in accordance with our hypothesis, F covered markedly more distance in the 2 fastest skating categories (Figure 4) despite the shorter time on ice. These types of differences between playing positions are consistently reported in several other team sports (7,13,35,38). Thus, the exercise intensity for a forward in the highest standard of competitive ice hockey is markedly higher than that of a defenseman, which should be taken into account when planning fitness training for a team. However, within the 2 out-field playing position groups, large individual differences were observed, indicating player-specific physical demands in ice hockey as previously shown in other team sports (4).

A limitation of the present study may be the relative small sample size, because the interindividual variations have been shown to be large in other team sports (11,13). However, the sample size was chosen in accordance with other studies on soccer (17–19,22,25–27), team handball (35) and basketball (38), Ultimate Frisbee (16), and ice hockey (33).

In conclusion, top-class ice hockey is a multiple-sprint sport with a higher exercise intensity than observed in other team sports. Moreover, players reach lower sprinting speeds in the latter half of a game than earlier in the game, indicating fatigue development. Forwards have a work profile characterized by markedly more high-intensity exercise in comparison to D. Moreover, high-intensity game activities during top-class match-play are correlated with cardiovascular loading during a submaximal ice-rink skating test, and the degree of muscle damage is partly associated with training status.

Practical Applications

Our findings demonstrate for the first time that top-class ice hockey is an intense intermittent sport with an activity pattern that has some similarities with other team sports. However, the amount of sprint and high-intensity skating occurs more frequently, which induces large demands on the ability of players to recover during and between shifts. Thus, these aspects should be taken into account in the daily training of competitive ice-hockey players. Fatigue seems to occur in the latter half of a game, and forewards have markedly greater requirements to perform repeated high-intensity exercise compared with defensemen. This means that coaches need to have a play-specific approach to physical preparation of ice-hockey players in different tactical roles. High-intensity skating performed in games is correlated with performance in a submaximal intermittent skating test. Thus, the YYIR1-IH_{SUB} test can be applied by coaches as an ice-hockey–specific test of physical capacity. Finally, the intense nature of the game implies that high-intensity intermittent training regimes such as aerobic high-intensity training and speed endurance training should therefore be given high priority in the physical preparation of ice-hockey athletes.

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