International Journal of Sports Physiology and Performance, 2023, 18, 458-464
https://doi.org/10.1123/ijspp.2022-0260

Human Kinetics
BRIEF REVIEW

A Framework for the Standardization of Game Analysis in Ice Hockey

Craig A. Staunton and Glenn Björklund
Department of Health Sciences, Swedish Winter Sports Research Center, Mid Sweden University, Östersund, Sweden

Background: Compared with other major global team sports such as football or basketball, ice hockey has received considerably less attention in sport-science research. However, the research focus on ice hockey performance is growing rapidly. Unfortunately, despite the growing interest in ice hockey, among the little research that has been conducted there are inconsistencies in terminology and methodology in the study of physiology and performance during games. The need for systematic and standardized reporting of study methodology is vital, as a lack of methodological detail or methodological inconsistencies make it impossible to replicate published studies, and alterations in the methodologies used can influence the measured demands imposed on players. Accordingly, this prohibits the ability of coaches to generate game-replicating training programs, decreasing the application of research findings to practice. In addition, a lack of methodological detail or methodological inconsistencies can result in incorrect conclusions being made from research. ***Purpose:*** In this invited commentary, we aim to increase awareness regarding the current standard of methodological reporting in ice hockey game-analysis research. In addition, we have developed a framework for the standardization of game analysis in ice hockey in order to allow for greater replication in future research and to increase the application of published findings to practice. ***Conclusions:*** We implore researchers in the field to consult the Ice Hockey Game Analysis Research Methodological Reporting Checklist in order to adopt a detailed reporting standard of methodologies in future work to help improve the applicability of research outcomes.

Keywords: checklist, methodological reporting, replication, performance analysis

Ice hockey is a global international team sport with 76 member countries of more than 1.6 million players registered in the International Ice Hockey Federation. Ice hockey games are characterized by explosive accelerations and decelerations on ice skates with frequent changes in speed and direction.[1–3] These movement patterns occur repetitively in 30- to 90-second intervals (or “shifts”) on ice, followed by a passive break of 3 to 5 minutes on the bench.[4,5] Thus, ice hockey performance is unique because it is predominantly supported by anaerobic metabolism. Nevertheless, the aerobic system is important for recovery to generate repeated high-intensity on-ice performance.[6,7]

Compared with other major global team sports, such as football or basketball, ice hockey has received considerably less attention in sports science research, however, research focus on ice hockey performance is growing rapidly. In demonstration of this, using the search terms (“ice hockey”) AND (“performance”) in PubMed yields 0 published studies in 2000, but as many as 62 published studies in 2021. Unfortunately, despite the growing interest in ice hockey research, among the little amount of research that does exist, there are inconsistencies in terminology and methodology in the study of physiology and performance during games.

The need for systematic and standardized reporting of study methodology is vital. This is true not only for ice hockey but also for all types of research. For example, previous reviews have highlighted the inconsistencies in methodological reporting of wearable sensor technology in sports.[8,9] A lack of methodological detail or methodological inconsistencies makes it impossible to replicate published studies, and alterations in the methodologies used can influence the measured demands imposed on players. Accordingly, this prohibits the ability of coaches to generate game-replicating training programs, decreasing the application of research findings to practice. In addition, a lack of methodological detail or methodological inconsistencies can result in incorrect conclusions being made from research.

As a result, we have developed this call to action to increase awareness regarding the current standard of methodological reporting in ice hockey-based game analysis research to allow for greater replication in future research and to increase the application of published findings to practice. We implore researchers in the field to adopt a detailed reporting standard of methodologies in future work to help improve the applicability of research outcomes.

Athlete Monitoring in Ice Hockey

As with most professional sports, athlete monitoring is vital in ice hockey for coaching and performance staff to optimize player and team performance. Through athlete monitoring, coaches and performance staff can understand the demands placed upon players during training and competitive games in order to optimize performance and minimize injury risk. Understanding the game and training demands can lead to the development of game-replicating training programs and permit coaches to prescribe an optimal training dose that increases performance and minimizes risk of either overtraining or undertraining. Accordingly, research in ice hockey has utilized various methods of athlete monitoring such as video time–motion analysis,[2,4] heart rate (HR) monitoring,[3,10–15] local positioning system technology,[16–18] and wearable sensor/accelerometer technology.[1,19–24] Primarily, these investigations

Björklund https://orcid.org/0000-0002-7781-8164
Staunton (craig.staunton@miun.se) is corresponding author, https://orcid.org/0000-0001-8023-1498

have focused on the game demands,[2–4,16,18,19] but some studies have also included analyses on the training demands.[1,10–15,20–23]

Time-Series Analysis

A common issue in the study of game demands in ice hockey (and team sports in general) is related to the method of "time-series analysis." Time-series analysis refers to the analysis of data recorded over an interval of time (eg, positioning systems, HR monitoring, or sensor-based data). A number of methods of time-series analysis for athlete monitoring data exist (readers are directed to Torres Ronda et al[25] for a thorough review). In addition, the use of local positioning system technology is emerging in ice hockey research. However, this brief review will not focus on methodological issues of these technologies as these have been highlighted previously.[8,9]

To date, ice hockey research has typically used an "epoch selection" time-series analysis method, whereby a certain time epoch is selected (eg, "total time," "time positioned on ice," and "effective playing time") in order to determine the game demands. Unfortunately, the method of epoch selection has been inconsistently applied in ice hockey research to date. For example, current ice hockey literature includes studies that have edited epochs to include only actual game play (ie, effective playing time),[1,2,4,16] studies that have edited epochs to remove only time between periods (ie, time positioned on ice),[3,21–23] and studies that have included warm-up within the epoch.[11,13–15] Furthermore, there are also studies that have altogether not reported what epoch was selected.[12,19,20] It is important to consider that game demands can differ drastically depending on the epoch analyzed. Accordingly, addressing the issues of inconsistency in epoch selection and terminology is of utmost importance to standardize methodological reporting. In order to avoid confusion between different epoch selection methods, it is first important to define commonly used epochs in ice hockey. This can help practitioners differentiate between the total time a player spends on the ice and the actual time spent playing the game. As such, we recommend the following terms and definitions be adopted in ice hockey research in order to permit the understanding of the time-series analysis and epoch selection approach used (Table 1).

In demonstration of the problem with inconsistent terminology and methodology around epoch selection, previous research has reported that full-length ice hockey games ranged from 116 to 125 minutes in duration.[11] Another study reported that official games lasted 58.9 (17.9) minutes.[14] These statements make little sense when an ice hockey game comprises three 20-minute periods of effective playing time, totaling 60 minutes of effective playing time (excluding overtime [OT]; see Section "Overtime"). Indeed, the inclusion of warm-up or "intermission time" within the epoch or by counting "time positioned on ice" rather than "effective playing time," might explain why sometimes the reported game durations are substantially greater than 60 minutes. However, it often remains unclear what the durations of pregame warm-ups were and how much contribution these make to the total game demand. Moreover, as far as we are aware, there are only 2 published studies that have examined ice hockey game demands that have reported effective playing time,[2,4] limiting the understanding of player demands during actual game play. As such, it is impossible for readers to separate data pertaining to warm-up, time positioned on ice, and the actual demands of game play if this information is not explicitly stated.

An important note with the following definitions relates to "effective playing time" and "time positioned on ice." With the inclusion of technology for the tracking of players during competitive games, it is often the total time a player is positioned on the ice (ie, time positioned on ice) and not the effective playing time that is recorded (ie, inclusive of time that players are on ice but the puck is not in play). This is obvious when studies report "time on ice" to be in excess of 30 minutes (eg, Rago et al[14] and Byrkjedal et al[17]), when the effective playing time in reality seldom exceeds 25 minutes in total. Accordingly, these terms have been developed to differentiate between the two. However, it must be noted that official statistics that often record effective playing time occasionally label these as "time on ice" (eg, https://www.nhl.com/stats/; https://www.shl.se/p/statistik/players), which is not to be confused with the term "time positioned on ice" suggested here.

The most appropriate epoch selection approach will likely depend on intended application of the data.[25] For example, aggregated or total values (eg, total distance skated) are limited in the prescription of game-replicating training programs, but might provide information pertaining to the total volume of game or training demands. Furthermore, mean values during epochs also have limited practical application. Preparing athletes for the average demands of game play will lead to underpreparation. Accordingly, it seems clear that more advanced techniques, such as moving averages, quantification of the peak demands (or "worst-case scenarios"), or even the application of time-series segmentation analysis (an analysis technique that comprises algorithms that search for change points within temporal data), will become more common in future studies. Regardless, researchers are implored to clearly report the time-series approach and the time epoch selected using consistent terminology (ie, Table 1) and with sufficient detail. Furthermore, we recommend that warm-up should be separated

Table 1 Key Terminology That Should Be Used in Ice Hockey Game Analysis Research

Term	Definition
Effective playing time	The total amount of time a player was involved in actual game play (ie, when the puck is in play and the clock is running). The maximum possible effective playing time a player can have is 60 min (excluding overtime). However, it is very rare for a player to accumulate more than 25 min of effective playing time in a single match. Note: Effective playing time is often recorded by official statistics and denoted as "time on ice (TOI)." Not to be confused with "time positioned on ice" as follows).
Time positioned on ice	The total amount of a time a player spends positioned on the ice, inclusive of both effective playing time as well as additional periods of time when a player is on ice but the puck is not in play. For example, when a whistle is blown for a penalty or icing. This is typically recorded by positioning system data and does not consider the actual game play.
Bench time	The total amount of time a player spends on the bench during the game.
Intermission time	The duration of time between the end of one period and the start of the next.
Total time	The total amount of time of the game, including time positioned on ice, as well as bench time and intermission time (ie, time positioned on ice + bench time + intermission time). Total time is accumulated from the moment of the first face-off to the final siren.

from game analyses. Warm-up is not representative of game-demands. If warm-up is included within the epoch selection, the duration must be clearly stated so that the reader can understand the relative contribution to the total exercise volume and/or intensity.

Overtime

OT presents a tricky scenario for ice hockey researchers in the fact that the regulations can vary between leagues and also between the regular season and playoffs. For example, with some regulations, OT periods are played with fewer players, different period durations, or played as a golden goal scenario. For example, the regular season OT regulations in the National Hockey League (NHL) stipulate a 5-minute OT period played 3v3, with a penalty shootout to follow if the game remains tied. Penalties during the OT period permit the team to add a player, not lose a player (eg, 4v3). However, the postseason playoff OT regulations in the NHL stipulate additional 20-minute OT periods played 5v5 with the same rules as regulation time. The game continues until a goal is scored with 15-minute intermissions between OT periods. Accordingly, OT periods can last as briefly as just a few seconds or as long as 20 minutes. Furthermore, it is not uncommon to have multiple OT periods when regulations stipulate no penalty shootouts. As such, the epoch selection during OT and the comparison to the 3 regular periods of game play present a challenge for ice hockey researchers because of the variability in activity duration or playing regulations.

Only 2 studies have reported physical demands during OT.[2,12] Unfortunately, one of these studies fails to report the number or duration of the OT period/s.[2] Although the average skating speed and distance per minute of activity in OT in this study were relatively comparable to the 3 regular periods, the accumulated high-speed skating distance was substantially lower compared with the regular periods, suggesting that there was only one OT period that did not go for the full 20 minutes.[2] In the other study to report the demands of OT,[12] the authors clearly articulate the OT period/s durations and regulations. In the postseason playoffs, OT comprised 20-minute periods, separated by 15-minute breaks until the first goal was scored. The authors reported that there were 2 games requiring OT, with one game finishing in the first OT period (12 min and 53 s) and the other game requiring 2 full additional OT periods (20 min each) and finishing in the third OT (74 s).

It is vital that ice hockey researchers separate OT periods from time-series analyses associated with competitive games. We, therefore, recommend that the duration, rules, and number of OT period/s must be reported clearly to permit a comprehensive understanding of the additional demands of OT period/s in ice hockey.

Rink Size

In contrast to many other team sports played across the world, the ice hockey playing area (rink) can differ in size, depending on country and competition. There are 3 different ice hockey rink sizes: North American (≈61 m × 26 m; 1586 m^2), intermediate ("Finnish size"; ≈60 m × 28 m; 1680 m^2), and international ("European size," 60 m × 30 m; 1800 m^2).[26] The biggest difference between the international and North American rinks is the end zones. The North American rinks are bigger and the neutral zone is consequently smaller (Figure 1). While the difference in rink size might seem negligible, this equates to a 13.5% increase in total rink area from the North American rink to the international rink. Accordingly, differences in rink size as well as differences in zone marking will likely influence playing demands. Previous research has demonstrated that pitch area and player density affect locomotor demands during small-sided games in soccer.[27–29] Accordingly, it is vital for ice hockey researchers to report the ice rink size used.

To date, most ice hockey research has been conducted on the smaller North American size rink. However, this information is often not explicitly reported or is left up to the reader to determine themselves. For example, several studies have reported that data collection took place during a specific tournament (eg, International Ice Hockey Federation world junior championships) or competition, sometimes with reporting the dates.[3,4,14–16,19,20] Accordingly, one can assume the rink size used based on the geographic location of the tournament (ie, North America or Europe). Only 2 studies[17,24] have specifically stipulated the rink size, while several studies have not provided sufficient information to determine the rink size used.[3,4,19,20] Because of the influence of the size of the playing arena on game demands, it is of utmost importance that ice hockey researchers clearly stipulate the rink size used.

Limitations of Psychophysiological Measures

HR has been measured in several ice hockey game analysis studies, where metrics such as the Bannister and the Edward training impulse have been reported in an attempt to describe the internal exercise volume (or so-called "internal load") during ice hockey games (eg, Ulmer et al,[10] Bigg et al,[11–13] Rago et al,[14,15] and Douglas et al[20]). Furthermore, other studies have reported average and peak HR as well as the time spent in certain HR intensity zones.[3,14,15] Ratings of perceived exertion (RPE)-based metrics have also been reported in several ice hockey game analysis studies.[11–15]

It is important to remember that HR has been promoted as a valid measure of exercise intensity because of strong associations with oxygen consumption and metabolic rate during steady-state submaximal intensity exercise.[30,31] Furthermore, RPE has been promoted as a valid surrogate for HR under the same submaximal, steady-state conditions.[32,33] However, HR measurement cannot provide an accurate measurement of the exercise intensity at any given point in time during intermittent exercise, which is problematic for designing game-replicating training programs in ice hockey. First, this is because the assumptions for HR representing metabolic intensity assume aerobic exercise conditions. Intermittent exercise, which has substantial anaerobic energy contributions, breaches these assumptions. Second, the delayed response of HR and $\dot{V}O_2$ kinetics at the onset of change in exercise intensity means that direct physiological measurement at any given point in time does not necessarily reflect the actual intensity of exercise being undertaken.[34] Steady-state HR and $\dot{V}O_2$ are not reached until about 3 minutes of continuous exercise at submaximal intensities.[34] When exercise is performed at intensities above lactate threshold, as is common during ice hockey, the HR and $\dot{V}O_2$ kinetics become even more complex and steady state is delayed even further.[34] Therefore, it is impossible for direct measurement of HR to quantify instantaneous exercise intensity during short-duration supramaximal intensity exercise bouts and rapid changes in movements. As such, HR measurement is an inappropriate assessment of instantaneous exercise intensity for ice hockey because of the high frequency of short-duration rapid movements and anaerobic energy contribution.[35–39]

In demonstration of this point, research has demonstrated that ice hockey games elicit high HR responses and large proportions of game duration in high-intensity HR zones. For example, Rago et al[14] reported peak HR values during games of 91% (7%) HR_{max}. In

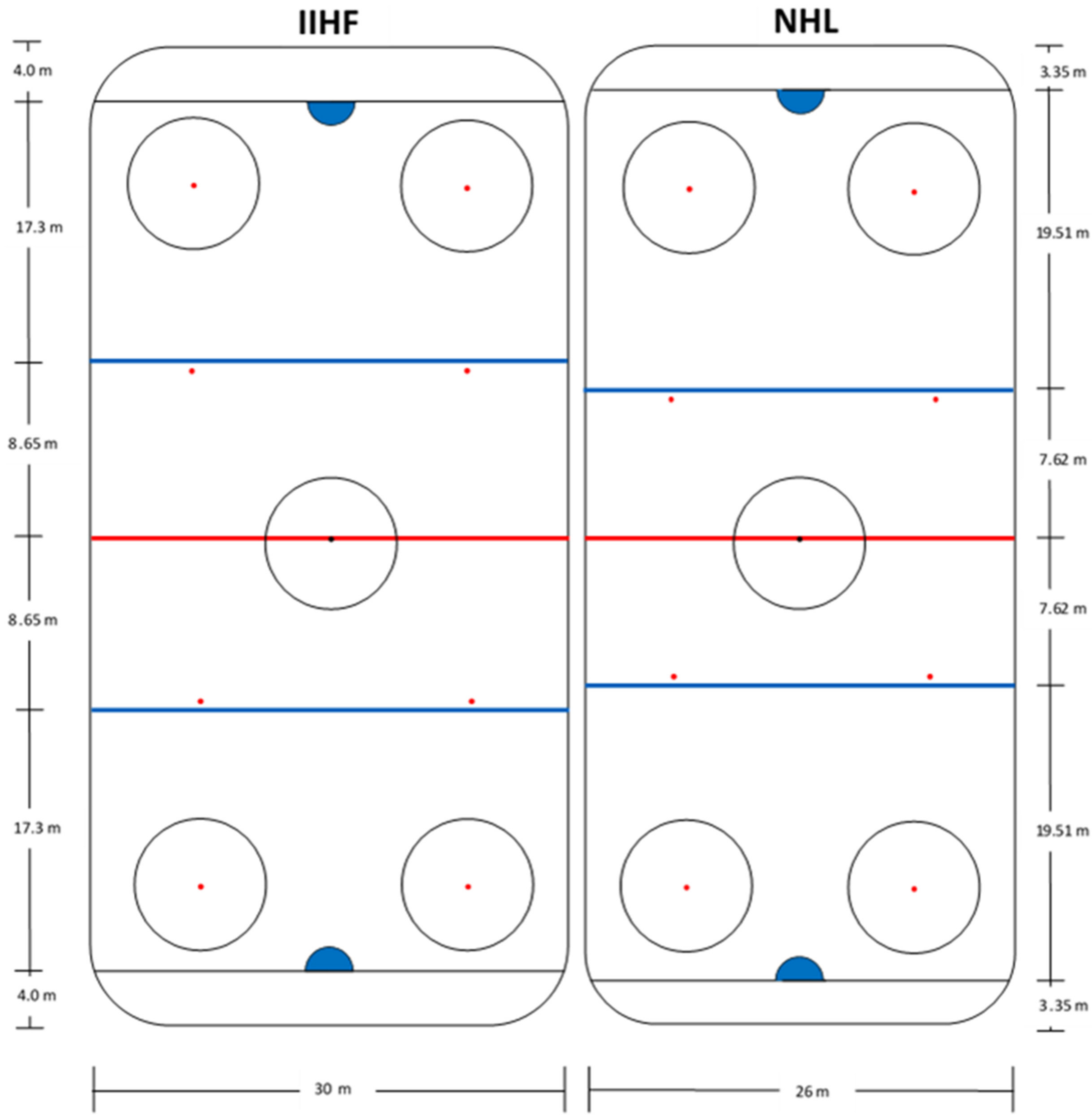

Figure 1 — The official ice-rink specifications for the IIHF (left) and the NHL (right). Note that the ice-rink size is 13.5% larger in the IIHF compared to the NHL. Although rink length is similar, there are differences in the layout, such as bigger neutral zone in (distance between the blue lines) in the IIHF. IIHF indicates International Ice Hockey Federation; NHL, National Hockey League.

addition, 24 (7) minutes of the game, out of a total "on-ice" time of 35 (7) minutes, was spent with a HR greater than 85% of maximum, equating to about 70% of "on-ice" duration. Therefore, a very high physiological demand is placed upon players during games. In contrast, research findings from video time–motion analyses report that just 17.6% (6%) of total effective playing time is spent performing high-intensity skating activities.[4] This disparity between the volume of high-intensity exercise clearly reflects the inability of physiological systems to respond to the rapid changes in intensity that occur frequently in high-intensity intermittent sports such as ice hockey. In addition, a meta-analysis, which investigated the validity of RPE, has revealed low correlations between RPE and HR (r = .36) during intermittent exercise.[40] Lower correlations between RPE and physiological variables during intermittent exercise are likely due to the inability of individuals to accurately recall the fluctuations of exercise intensity experienced over the duration of intermittent exercise. Accordingly, this also likely impacts the ability of players to provide an accurate session RPE score during ice hockey gameplay and the subsequent calculation of session RPE-based "training load" scores. Furthermore, RPE scores are subject to emotion[41] and a variety of external factors, which are difficult to control, such as psychological factors.[33] Definitive studies examining the validity of RPE as well as session RPE within ice hockey are warranted; however, it seems clear that subjective perceptual measures should be monitored during exercise in combination with other measures of intensity or dose.[42] Objective measurement is required to isolate the external components of perceived exertion from the actual exercise dose received by athletes.

Despite this, some studies in ice hockey have solely reported HR and RPE-based measures to describe the demands of the game (eg, Bigg et al[11–13]). It is acknowledged that HR and RPE-based measurements are highly practical tools that can at least provide some insights into the internal demands placed upon players. For example, physiological responses might overestimate and underestimate intensity at various stages throughout the duration of ice hockey activity. Therefore, the average physiological response over the duration of a game might balance and provide a reasonable measurement of average exercise intensity. However, physiological measures of exercise intensity in ice hockey lack utility. These data alone provide little understanding of the exercise demands during ice hockey. Accordingly, ice hockey researchers are implored to combine measures of the both internal and external intensities to fully understand the demands placed upon players during competitive games.

Accelerometry/Inertial Measurement Units

Accelerometer technology could be a highly valuable tool for monitoring the external exercise demands in ice hockey. These small, wearable devices can be used to measure all fatiguing demands, not just locomotion.[43] This can include efforts related to collisions and checking. Therefore, accelerometers are very well suited to quantify the external exercise demands associated with ice hockey. Despite the potential benefits of accelerometer technology to describe game demands in ice hockey, there has been a notable increased use of proprietary sensor-based variables with insufficient methodological detail provided to permit replication. The use of these proprietary metrics is characterized by reporting in arbitrary units, the use of arbitrary threshold cutoffs without justification, and a lack of prior validation for quantification of the construct that it claims to measure.

While some metrics have clearly reported Cartesian formulas (eg, PlayerLoad or Skating Load; Catapult Sports), which are highly beneficial for reproducing calculations, there are still issues pertaining to undocumented filtering and analysis techniques conducted within commercial software.[44] For example, previous research has identified that the PlayerLoad reported from the manufacturer software differs to that from the reported formula, indicating additional data manipulation not reported by device manufacturers.[44] It is natural that commercial companies do not want to disclose all information on their calculations; however, researchers must be aware that the numbers generated from these software systems have been manipulated. Accordingly, PlayerLoad or Skating Load values should be interpreted with caution, especially when using the reported formulas to calculate these metrics with different hardware devices. Furthermore, there are other metrics that simply do not provide enough information for replication. For example, "explosive efforts" (EE) is a metric that has been reported in several ice hockey game analysis studies.[1,19–23] EE is a metric that claims to be a frequency count of explosive movements performed by an athlete. It is designed to count the number of high-intensity movements, including rapid accelerations and decelerations, high-intensity skating, and rapid changes of direction (skating based or body contact). EE has been defined as follows in previous research[20]:

> This count [EE] was derived from IMA data. For an event to be recorded as an explosive effort, a polynomial least squares fit was applied to the *x*, *y*, and *z* resultant acceleration data and smoothed at a known frequency. This smoothed trace was overlaid with the original acceleration trace, and the start and end point of the event was identified. Once identified, the sum of the *x*, *y* area was calculated and expressed as the event magnitude (in meters per second). Any identified movement that occurred at a rate greater than 2 $m \cdot s^{-1}$ in any direction was counted. (p. 1228)

This definition does not provide sufficient information to replicate the calculation with raw accelerometer data or data derived from another system. For example, the exact smoothing frequency used is not provided, the order of the polynomial fitted to the acceleration data is not defined, the event start and end point identification is ambiguous, and the method of cross-correlation (overlaying of acceleration signals) is insufficiently described to permit replication.

Misunderstanding of the calculation of this metric probably explains why the range of EE reported in ice hockey games has such great variability. For example, Neeld et al[22] reported 463 (128) EE for forward and 423 (96) EE for defenders during NCAA Division 1 men's games. Meanwhile, Douglas et al[19–21] reported EE in 3 separate studies on elite female hockey players. In one study, there was 344 (73) EE for forward and 301 (61) EE for defenders during national team competitions.[20] In another study, there was 1361 (235) EE for forward and 1374 (342) EE for defenders during a preseason competition.[21] Finally, in another study there was a mean total over 3 periods of 2946 EE for forward and 1352 EE for defenders during national team games.[19] It is unrealistic that the actual number of explosive efforts required in games differs so drastically within a similar population group.

The large variation in the magnitude of the metrics reported between studies demonstrates the fact that standardization of accelerometer-derived metrics is required. In fact, recent research has demonstrated that adopting a common data filtering process greatly limits between-device differences in acceleration-related metrics.[45] Researchers must be cognizant of the limitations associated with proprietary metrics and should be more critical of metrics that are insufficiently described. Furthermore, exercise-related metrics should ideally be reported in physical quantities.[46] Given the fact that acceleration naturally has an SI-derived unit (in meters per second squared), it is unnecessary to report accelerometer-derived metrics in arbitrary units.[47] While these commercial metrics hold great practical value given their ease of use for consumers, sufficient information pertaining to how the metric is calculated must be included in scientific publications. For example, the explicit name of the software and its version must be included to permit replication. Journal editors, reviewers, and individual researchers should be cognizant and more critical of this.

Practical Applications

To ensure that adequate methodological detail is provided for interpretation and replication in future ice hockey game analysis research, we developed the "ice hockey game analysis research methodological reporting checklist." This checklist contains a list of questions that researchers should be able to clearly answer with

Table 2 Ice Hockey Game Analysis Research Methodological Reporting Checklist

	Question	
☐	Has standardized terminology been used to describe ice hockey game play?	Table 1
☐	Has the epoch selection for time-series analysis been clearly articulated (if applicable)?	Section "Time-Series Analysis"
☐	If included, has the warm-up been separated from analysis and the duration reported?	Section "Time-Series Analysis"
☐	If included, has the overtime period/s been separated from analysis and the duration/s and regulations reported?	Section "Overtime"
☐	Has the rink size been clearly stipulated?	Section "Rink Size"
☐	If physiological measures have been used, have these been reported with other measures of external demand?	Section "Limitations of Psychophysiological Measures"
☐	If accelerometer-based metrics are reported, have the calculations been clearly described with enough detail to permit replication?	Section "Accelerometry/Inertial Measurement Units"

precise detail within the methods section of future studies (Table 2). In particular, researchers are asked to (1) use standardized terminology when referring to ice hockey epochs, (2) clearly stipulate the epoch selection used in time-series analysis, (3) separate warm-up from game analyses and report the duration if warm-up is included, (4) separate OT period/s from game analyses and report the duration and regulations, (5) stipulate the rink size used in the analysis, (6) only report physiological measures in combination with measures of external demand, and (7) be wary of proprietary accelerometer-based metrics; these must be described with sufficient detail to permit replication.

Conclusions

The current methodological standard in ice hockey research is insufficient to permit replication. Variability in methodology, such as epoch selection, inclusion of warm-up in game analysis, failure to report rink size, sole use of physiological variables in a high-intensity intermittent sport, and the use of proprietary accelerometer-based metrics, is limiting the application of research to practice. Consequently, we have developed a framework for the standardization of key terminology to be used in ice hockey research (Table 1). Furthermore, the Ice Hockey Game Analysis Research Methodological Reporting Checklist (Table 2) can guide researchers to improve methodological reporting standards, which can permit greater understanding of research and application to practice.

References

1. Allard P, Martinez R, Deguire S, Tremblay J. In-season session training load relative to match load in professional ice hockey. *J Strength Cond Res*. 2020;36(2):486–492. doi:10.1519/JSC.0000000000003490
2. Lignell E, Fransson D, Krustrup P, 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*. 2018;32(5):1303–1310. PubMed ID: 28557852 doi:10.1519/JSC.0000000000001999
3. Stanula AJ, Gabryś TT, Roczniok RK, Szmatlan-Gabryś UB, Ozimek MJ, Mostowik AJ. Quantification of the demands during an ice-hockey game based on intensity zones determined from the incremental test outcomes. *J Strength Cond Res*. 2016;30(1):176–183. PubMed ID: 26154153 doi:10.1519/JSC.0000000000001081
4. Brocherie F, Girard O, Millet GP. Updated analysis of changes in locomotor activities across periods in an international ice hockey game. *Biol Sport*. 2018;35(3):261. PubMed ID: 30449944 doi:10.5114/biolsport.2018.77826
5. Green H, Bishop P, Houston M, McKillop R, Norman R, Stothart P. Time-motion and physiological assessments of ice hockey performance. *J Appl Physiol*. 1976;40(2):159–163. PubMed ID: 1248994 doi:10.1152/jappl.1976.40.2.159
6. Carey DG, Drake MM, Pliego GJ, Raymond RL. Do hockey players need aerobic fitness? Relation between VO_2max and fatigue during high-intensity intermittent ice skating. *J Strength Cond Res*. 2007;21(3):963. PubMed ID: 17685680
7. Peterson BJ, Fitzgerald JS, Dietz CC, et al. Aerobic capacity is associated with improved repeated shift performance in hockey. *J Strength Cond Res*. 2015;29(6):1465–1472. PubMed ID: 25756322 doi:10.1519/JSC.0000000000000786
8. Varley MC, Jaspers A, Helsen WF, Malone JJ. Methodological considerations when quantifying high-intensity efforts in team sport using global positioning system technology. *Int J Sports Physiol Perform*. 2017;12(8):1059–1068. PubMed ID: 28051343 doi:10.1123/ijspp.2016-0534
9. Malone JJ, Lovell R, Varley MC, Coutts AJ. Unpacking the black box: applications and considerations for using GPS devices in sport. *Int J Sports Physiol Perform*. 2017;12(suppl 2):S2-18–S2-26. doi:10.1123/ijspp.2016-0236
10. Ulmer JG, Tomkinson GR, Short S, Short M, Fitzgerald JS. Test-retest reliability of TRIMP in collegiate ice hockey players. *Biol Sport*. 2019;36(2):191. PubMed ID: 31223197 doi:10.5114/biolsport.2019.84670
11. Bigg JL, Gamble AS, Spriet LL. Internal load of male varsity ice hockey players during training and games throughout an entire season. *Int J Sports Physiol Perform*. 2021;17(2):286–295. doi:10.1123/ijspp.2021-0089
12. Bigg JL, Gamble AS, Spriet LL. Internal physiological load measured using training impulse in varsity men's and women's ice hockey players between game periods. *J Strength Cond Res*. 2021;35(10):2824–2832. PubMed ID: 34417402
13. Bigg JL, Gamble ASD, Spriet LL. Internal load of female varsity ice hockey players during training and games during a season. *Int J Sports Med*. 2021;43(4):357–365. PubMed ID: 34638142
14. Rago V, Vigh-Larsen JF, Deylami K, Muschinsky A, Mohr M. Use of rating of perceived exertion-based training load in elite ice hockey training and match-play. *J Strength Cond Res*. 2020;36(10):2837–2843. PubMed ID: 33370008 doi:10.1519/JSC.0000000000003915
15. Rago V, Muschinsky A, Deylami K, Mohr M, Vigh-Larsen JF. Weekly training load in elite male ice hockey: practice versus competition demands. *Int J Sports Physiol Perform*. 2021;

17(2):270–277. PubMed ID: 34686613 doi:10.1123/ijspp.2021-0188

16. Douglas AS, Kennedy CR. Tracking in-match movement demands using local positioning system in world-class men's ice hockey. *J Strength Cond Res*. 2020;34(3):639–646. doi:10.1519/JSC.0000000000003414
17. Byrkjedal PT, Luteberget LS, Bjørnsen T, Ivarsson A, Spencer M. Simulated game-based ice hockey match design (scrimmage) elicits greater intensity in external load parameters compared with official matches. *Front Sports Act Living*. 2022;4:822127. doi:10.3389/fspor.2022.822127
18. Gamble ASD, Bigg JL, Nyman DLE, Spriet LL. Local positioning system-derived external load of female and male varsity ice hockey players during regular season games. *Front Physiol*. 2022;13:831723. doi:10.3389/fphys.2022.831723.
19. Douglas A, Johnston K, Baker J, Rotondi MA, Jamnik VK, Macpherson AK. On-ice measures of external load in relation to match outcome in elite female ice hockey. *Sports*. 2019;7(7):173. PubMed ID: 31315209 doi:10.3390/sports7070173
20. Douglas A, Rotondi MA, Baker J, Jamnik VK, Macpherson AK. On-ice physical demands of world-class women's ice hockey: from training to competition. *Int J Sports Physiol Perform*. 2019;14(9):1227–1232. doi:10.1123/ijspp.2018-0571
21. Douglas AS, Rotondi MA, Baker J, Jamnik VK, Macpherson AK. A comparison of on-ice external load measures between subelite and elite female ice hockey players. *J Strength Cond Res*. 2020;36(7):1978–1983. PubMed ID: 32796414 doi:10.1519/JSC.0000000000003771
22. Neeld K, Peterson B, Dietz C, Cappaert T, Alvar B. Differences in external workload demand between session types and positions in collegiate men's ice hockey. *Int J Kinesiol Sports Sci.*. 2021;9(1):36–44. doi:10.7575/aiac.ijkss.v.9n.1p.36
23. Neeld KL, Peterson BJ, Dietz CC, Cappaert TA, Alvar BA. Impact of preceding workload on team performance in collegiate men's ice hockey. *J Strength Cond Res*. 2021;35(8):2272–2278. PubMed ID: 34127608 doi:10.1519/JSC.0000000000004076
24. Perez J, Brocherie F, Couturier A, Guilhem G. International matches elicits stable mechanical workload in high-level female ice hockey. *Biol Sport*. 2022;39(4):857–864. PubMed ID: 36247938 doi:10.5114/biolsport.2022.109455
25. Torres-Ronda L, Beanland E, Whitehead S, Sweeting A, Clubb J. Tracking systems in team sports: a narrative review of applications of the data and sport specific analysis. *Sports Med*. 2022;8(1):1–22. doi:10.1186/s40798-022-00408-z
26. Popkin CA, Schulz BM, Park CN, Bottiglieri TS, Lynch TS. Evaluation, management and prevention of lower extremity youth ice hockey injuries. *Open Access J Sports Med*. 2016;7:167. PubMed ID: 27920584 doi:10.2147/OAJSM.S118595
27. Santos FJ, Verardi CE, de Moraes MG, et al. Effects of pitch size and goalkeeper participation on physical load measures during small-sided games in sub-elite professional soccer players. *Appl Sci*. 2021;11(17):8024. doi:10.3390/app11178024
28. Lacome M, Simpson BM, Cholley Y, Buchheit M. Locomotor and heart rate responses of floaters during small-sided games in elite soccer players: effect of pitch size and inclusion of goalkeepers. *Int J Sports Physiol Perform*. 2018;13(5):668–671. PubMed ID: 28952828 doi:10.1123/ijspp.2017-0340
29. Castellano J, Puente A, Echeazarra I, Casamichana D. Influence of the number of players and the relative pitch area per player on heart rate and physical demands in youth soccer. *J Strength Cond Res*. 2015;29(6):1683–1691. PubMed ID: 25474336 doi:10.1519/JSC.0000000000000788
30. Hopkins W. Quantification of training in competitive sports. *Sports Med*. 1991;12(3):161–183. PubMed ID: 1784872 doi:10.2165/00007256-199112030-00003
31. Borresen J, Lambert MI. The quantification of training load, the training response and the effect on performance. *Sports Med*. 2009;39(9):779–795. doi:10.2165/11317780-000000000-00000
32. Borg G. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*. 1982;14(5):377–381. PubMed ID: 7154893 doi:10.1249/00005768-198205000-00012
33. Borg G. *Borg's Perceived Exertion and Pain Scales*. 1998; Human Kinetics.
34. Xu F, Rhodes EC. Oxygen uptake kinetics during exercise. *Sports Med*. 1999;27(5):313–327. PubMed ID: 10368878 doi:10.2165/00007256-199927050-00003
35. Abdelkrim NB, El Fazaa S, El Ati J. Time–motion analysis and physiological data of elite under-19-year-old basketball players during competition. *Br J Sports Med*. 2007;41(2):69–75. PubMed ID: 17138630 doi:10.1136/bjsm.2006.032318
36. Conte D, Favero TG, Lupo C, Francioni FM, Capranica L, Tessitore A. Time-motion analysis of Italian elite women's basketball games: individual and team analyses. *J Strength Cond Res*. 2015;29(1):144–150. PubMed ID: 25051006 doi:10.1519/JSC.0000000000000633
37. Scanlan A, Dascombe B, Reaburn P. A comparison of the activity demands of elite and sub-elite Australian men's basketball competition. *J Sports Sci*. 2011;29(11):1153–1160. PubMed ID: 21777151 doi:10.1080/02640414.2011.582509
38. Montgomery DL. Physiology of ice hockey. *Sports Med*. 1988;5(2):99–126. PubMed ID: 3281210 doi:10.2165/00007256-198805020-00003
39. Cox MH, Miles DS, Verde TJ, Rhodes EC. Applied physiology of ice hockey. *Sports Med*. 1995;19(3):184–201. PubMed ID: 7784758 doi:10.2165/00007256-199519030-00004
40. Chen M, Fan X, Moe ST. Criterion-related validity of the Borg ratings of perceived exertion scale in healthy individuals: a meta-analysis. *J Sports Sci*. 2002;20(11):873–899. PubMed ID: 12430990 doi:10.1080/026404102320761787
41. Baden D, McLean T, Tucker R, Noakes T, Gibson ASC. Effect of anticipation during unknown or unexpected exercise duration on rating of perceived exertion, affect, and physiological function. *Br J Sports Med*. 2005;39(10):742–746. PubMed ID: 16183771 doi:10.1136/bjsm.2004.016980
42. Halson SL. Monitoring training load to understand fatigue in athletes. *Sports Med*. 2014;44(suppl 2):139–147. doi:10.1007/s40279-014-0253-z
43. Boyd LJ, Ball K, Aughey RJ. The reliability of MinimaxX accelerometers for measuring physical activity in Australian football. *Int J Sports Physiol Perform*. 2011;6(3):311–321. PubMed ID: 21911857 doi:10.1123/ijspp.6.3.311
44. Nicolella DP, Torres-Ronda L, Saylor KJ, Schelling X. Validity and reliability of an accelerometer-based player tracking device. *PLoS One*. 2018;13(2):e0191823. doi:10.1371/journal.pone.0191823
45. Delves RIM, Duthie GM, Ball KA, Aughey RJ. Applying common filtering processes to Global Navigation Satellite System-derived acceleration during team sport locomotion. *J Sports Sci*. 2022;40(10):1116–1126. PubMed ID: 35282785 doi:10.1080/02640414.2022.2051332
46. Winter EM, Fowler N. Exercise defined and quantified according to the Systeme International d'Unites. *J Sports Sci*. 2009;27(5):447–460. doi:10.1080/02640410802658461
47. Staunton CA, Abt G, Weaving D, Wundersitz DW. Misuse of the term 'load' in sport and exercise science. *J Sci Med Sport*. 2021;25(5):439–444. doi:10.1016/j.jsams.2021.08.013