UNIVERSITAT DE BARCELONA

# Valoració de les demandes de càrrega externa i interna en l'hoquei patins

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Tesis doctoral:

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# VALORACIÓ DE LES DEMANDES DE CÀRREGA EXTERNA I INTERNA EN L'HOQUEI PATINS

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“The best way to scare a Tory

is to read and get rich”

IDLES

## Agraïments

El camí que es tanca amb el dipòsit i defensa d’aquesta tesi és un camí que no he fet sol. Ans al contrari, és un camí que tan sols he pogut recórrer gràcies al suport, acompanyament i cura de tanta gent que ha estat al meu costat fins i tot abans de ser conscient de començar aquest camí. A totes aquelles persones que heu estat presents, que heu tingut un temps per a mi, que heu revisat quelcom, que m’heu enviat algun missatge en hores que no hauríeu de fer-ho, les que seran mencionades i les que em deixi de mencionar, gràcies.

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# Resum

Aquesta tesi té com a objectiu principal analitzar la càrrega externa i interna en l'hoquei patins d'elit i explorar les seves aplicacions pràctiques. L'hoquei patins és un esport exigent físicament i comprendre les demandes associades al joc és crucial per a l'optimització de l'entrenament i el rendiment dels jugadors. Aquesta tesi s'enfoca en la quantificació de la càrrega externa (variables relacionades amb el treball realitzat pels jugadors) i interna (resposta fisiològica i perceptual dels jugadors) per proporcionar una visió completa de les demandes físiques del joc. Per aconseguir aquest objectiu, es van realitzar diversos estudis en un equip d'hoquei patins d'elit. Es van recollir dades de càrrega externa mitjançant sistemes de seguiment LPS i acceleròmetres, així com dades de càrrega interna a través de la percepció subjectiva de l'esforç i altres mesures fisiològiques. Aquesta combinació de mètodes va permetre una anàlisi detallada de les demandes físiques dels jugadors en diferents contextos de joc i entrenament.

Els resultats d'aquesta investigació han revelat que no hi ha diferències significatives en les variables de càrrega externa entre les posicions d'exterior i interior en partits oficials. A més, s’han proporcionat referències de volums i intensitats d'entrenament descobrint una tendència a reduir tant càrrega interna com externa a mesura que s’apropa el dia de partit. La repetició d'escenaris de diferent intensitat s’ha pogut identificar com una mètrica valuosa per controlar la càrrega externa durant el cicle d'entrenament i permetre una comparació efectiva amb les demandes dels partits. A més, s’ha evidenciat que la reducció de l'espai de joc en els partits d'entrenament no només redueix la distància recorreguda pels jugadors, sinó que també manté les demandes d'acceleracions i desacceleracions al mateix nivell que en un partit a pista completa.

Les troballes d'aquesta tesi tenen implicacions importants per als entrenadors i preparadors físics. En conclusió, aquesta tesi proporciona una comprensió més profunda de la càrrega externa i interna en l'hoquei patins d'elit i intenta oferir també una orientació pràctica. L'anàlisi de la càrrega externa i interna és fonamental per a l'adequació dels programes d'entrenament i la optimització del rendiment. Finalment, el nostre treball aporta noves evidències científiques que contribueixen a la millora del rendiment en l'hoquei patins d'elit.

# Abstract

This thesis aims to analyze the external and internal load in elite rink hockey and explore its practical applications. Rink hockey is a physically demanding sport, and understanding the demands associated with the game is crucial for optimizing training and player performance. The thesis focuses on quantifying the external load (variables related to the work performed by the players) and internal load (physiological and perceptual response of the players) to provide a comprehensive understanding of the physical demands of the game. To achieve this objective, several studies were conducted on an elite roller hockey team. External load data were collected using LPS tracking systems and accelerometers, while internal load data were obtained through subjective ratings of perceived exertion and other physiological measures. This combination of methods allowed for a detailed analysis of the players' physical demands in different game and training contexts.

The results of this research revealed no significant differences in external load variables between the interior and exterior player positions in official matches. Additionally, references for training volumes and intensities were provided, showing a tendency to reduce both internal and external load as the match day approached. The repetition of different intensity scenarios was identified as a valuable metric for monitoring external load during the training cycle and enabling effective comparison with match demands. Furthermore, it was found that reducing the playing space in training matches not only reduced the distance covered by the players but also maintained acceleration and deceleration demands at the same level as in full-court matches.

These findings have important implications for coaches and sport scientists. In conclusion, this thesis provides a deeper understanding of the external and internal load in rink hockey and offers practical guidance. Analyzing external and internal load is crucial for adapting training programs and optimizing performance. Our work presents new scientific evidence that contributes to the improvement of performance in elite rink hockey.

# Índex

## Índex de figures

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## Glossari d’abreviatures

| | |
|---|---|
| EPTS | *Electronic performance  tracking system* |
| LPS | *Local positioning system* |
| GPS | *Global positioning system* |
| IMU | *Inertial measurement unit* |
| RPE | *Rate of perceived effort* |
| sRPE | *Session rate of perceived effort* |
| DT | *Distance travelled* |
| HSS | *High speed skating* |
| PL | *Player Load* |
| ACC | *High intensity acceleration* |
| DEC | *High intensity deceleration* |
| DP | *Dia de partit* |
| FCmax | *Freqüència cardíaca màxima* |

*Les abreviatures utilitzades en la redacció dels manuscrits no estan incloses.

# Capítol 1.

# Marc teòric

# 1. Motivacions de l’autor i antecedents de la tesis

Aquesta tesis doctoral sorgeix de tota una vida dedicada a l’hoquei patins. L’any 2016, el que havia estat fins el moment un esport que practicava des de petit, va passar a ser una feina. Durant la meva discreta trajectòria com a jugador, vaig estudiar ciències de l’esport ja que la meva vida girava al voltant de l’activitat física i això va permetre’m passar de jugador a preparador físic. El fitxatge pel primer equip d’hoquei patins del Futbol Club Barcelona com a preparador físic va canviar la meva vida per complet, quan tot just tenia 25 anys. A partir d’aquell moment sorgeix la necessitat de trobar informació per poder millorar la feina que realitzo cada dia, aquesta necessitat va passar a ser part fonamental de la meva ocupació diària. A la vegada, l’aparició i l’ús de sistemes electrònics de seguiment de forma transversal en tots els equips professionals del club, va provocar una recollida de dades i informació ingent, que va permetre tenir informació fins el moment mai vista en tots els esports professionals del club.

Per altra banda, la realitat actual en l’hoquei patins és regida per una bibliografia científica quasi nul·la. La majoria d’aquesta prové de la dècada del 1990 quan l’hoquei patins va ser esport d’exhibició als Jocs Olímpics de Barcelona 92 (excepte una publicació feta l’any 2009). Per tant, la manca d’informació en el nostre esport és tant brutal en comparació amb altres esports d’equip, que la sensació estesa i compartida entre tots els professionals és que sempre hem estat un pas endarrere.

Just quan aquesta combinació: moltes dades recollides i poca informació trobada, va arribar al seu punt àlgid la temporada 2019/2020, va néixer un projecte de recerca on la idea principal va ser aportar coneixement sobre el control de càrregues i la descripció de les demandes físiques en la competició i l’entrenament. Aquest projecte finalment es va recolzar en les figures d’en Gerard Carmona (company de feina al club i l’acadèmia) i en Joan Aureli Cadefau des de l’INEFC de Barcelona. A finals de l’any 2020, el projecte s’oficialitzà amb la inscripció i matriculació d’aquest al programa HDK02 - Activitat Física, Educació Física i Esport; sent així aquest el tret de sortida a aquesta tesis.

# 2. Fonamentació teòrica

## 2.1. L'hoquei patins

L'hoquei patins és un joc que es practica en un terreny de joc rectangular, de superfície llisa, on dos equips de cinc jugadors cada un (un d'ells porter) competeixen entre ells (Figura 1); destaca l'ús de patins amb rodes que estan col·locades de forma paral·lela al voltant de dos eixos transversals i on la bola tan sols es pot colpejar o conduir amb un estic. L'objectiu principal del joc és introduir la bola a la porteria amb l'estic (Torner, 1984). Existeixen altres definicions de l'esport, Sénica (2004) defineix l'hoquei patins com un joc de col·laboració / oposició, on s'utilitza un implement per poder fer accions amb la bola i on els jugadors es desplacen per la pista mitjançant patins. L'objectiu principal és introduir la bola a la porteria contraria i el joc es regeix per unes normes comunes.

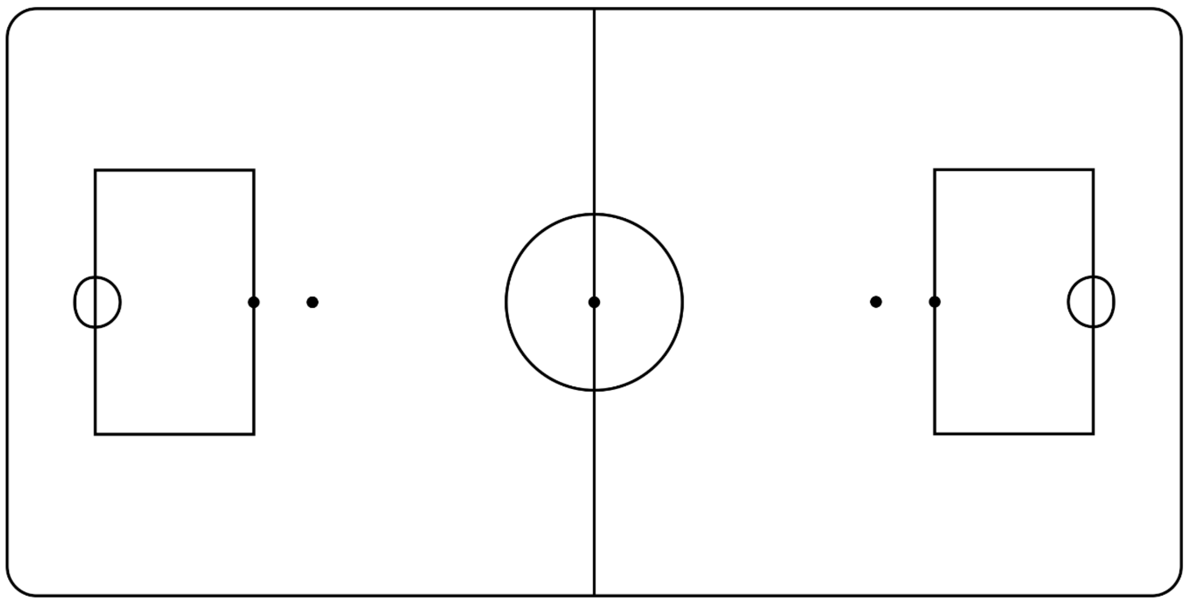

*Figura 1. Terreny de joc d'hoquei patins, 40 metres de llarg per 20 metres d'ample, amb els límits del terreny de joc delimitats per tanques.*

Podem definir l'hoquei patins doncs com un esport col·lectiu. Seguint la classificació de (Parlebas, 2001), l'hoquei patins com altres esports d'estructura similar (futbol sala, bàsquet o handbol). És un esport on trobem adversaris i companys simultàniament, provocant incertesa en totes les accions de joc que es puguin donar d'aquesta relació. A la vegada, però on no hi ha incertesa sobre el terreny de joc.

Des d'una perspectiva general, el fet diferencial que caracteritza l'hoquei patins és que només es permet desplaçar als jugadors per la pista amb patins i prendre contacte amb la bola mitjançant un implement, l'estic (Figura 2). Precisament, l'ús d'aquests implements "no naturals" durant la practica de l'esport, fa que conceptes bàsics de psicomotricitat com l'esquema corporal, la dinàmica motriu i l'organització perceptiva – motriu es vegin sensiblement alterats. Aquestes alteracions són les que fan de l'hoquei patins un esport, des del punt de vista psicomotriu, altament complex dins dels esports col·lectius, tant en etapes de iniciació com de rendiment (Paüls, 2018).


*Figura 2. Jugadors amb el material característic de l'hoquei patins: patins, estic i proteccions en el tronc inferior.*

A diferència de les anteriors definicions, existeixen anàlisis més concrets des de diferents punts de vist: tècnic, tàctic o model de joc. En el nostre cas, pel caràcter de la tesis, en aquesta recerca tant sols realitzarem un anàlisis més profund des de l'estructura condicional d'aquest esport. La referencia més antiga en aquest sentit és de (Manaças, 1988), on l'autor exposa que l'hoquei patins reclama d'una extraordinària preparació física conjuntament amb un excel·lent domini de la tècnica i tàctica individual. Des del punt de vista fisiològic, l'hoquei patins és considerat un esport aeròbic i anaeròbic altern, combinant l'existència de moments d'intensitat molt elevada, amb altres moments d'intensitat moderada (Rodríguez et al., 1991) i aquesta alternança entre moments de diferent intensitat és així de variable degut a la dinàmica del joc i les seves situacions (Blanco et al., 1993). Per altra banda, des del punt de vista de les demandes condicionals, Aguado (1991) i Merino Tantiña et al. (2014) van analitzar l'activitat realitzada per jugadors de pista durant partits de la màxima categoria nacional, coincidint ambdós en que l'hoquei patins té un caràcter intermitent amb recuperacions incompletes, amb una realització alternada d'esforços d'alta, moderada i baixa intensitat.

La resta de recerca sobre l'hoquei patins té un marcat caràcter tècnic – tàctic, el qual s'allunya dels objectius i rerefons d'aquesta tesis. El fet més remarcable sobre la investigació en hoquei patins és l'aparició d'un article de revisió sobre l'esport (Sousa et al., 2022) on s'indica que la majoria de bibliografia de temàtica condicional és publicada abans de la temporada 2009/2010, on la federació internacional de patinatge (*World Skate*), va proposar un seguit de noves normes per incentivar un joc més atractiu, ràpid i amb menys contacte. El canvi de normativa que l'esport va sofrir l'any 2009 pot ser que fos el responsable d'un augment de les accions realitzades a més de 6 m/s passant d'un 11% a un 31% del total de les accions realitzades en un partit (Merino Tantiña et al., 2014).

## 2.2. Control de la càrrega

Tant l'hoquei patins com la resta d'esports d'equip són activitats transversalment exigents i quan els jugadors practiquen aquests esports en nivells de competició alts, tant l'entrenament com les competicions provoquen adaptacions fisiològiques dels sistemes cardiovascular i muscular. Aquestes adaptacions beneficien el rendiment físic mitjançant l'augment de la resistència, la velocitat o la força; i en conseqüència el rendiment esportiu podria veure's positivament afectat (sent conscients de que en entorns complexes i estocàstics com els esports d'equip més no vol dir sempre millor). No obstant això, una quantitat excessiva d'entrenament pot provocar una sobrecàrrega de la capacitat dels jugadors; i rebre un estímul insuficient durant entrenament o competició pot reduir la capacitat anteriorment citada. Els estímuls presentats als jugadors, també coneguts com càrrega de treball, en el context de l'entrenament esportiu s'han definit com una variable d'entrada que, assumint un cert nivell d'estrès, es manipula per obtenir la resposta desitjada (Impellizzeri et al., 2019). Si bé la càrrega d'entrenament és totalment manipulable, la càrrega de competició, per les seves característiques intrínseques com el resultat, el lloc a la classificació (propi i del rival), l'etapa de la temporada o el tipus de lliga, ho és molt menys i es limita a la possibilitat de regular l'exposició dels jugadors a aquesta mitjançant els minuts de joc. La càrrega es pot descriure com a interna o externa (Impellizzeri et al., 2019). La càrrega externa és el treball realitzat pel jugador independentment de les seves característiques internes; es descriu per exemple, en termes de distància, acceleracions, desacceleracions o esprints, entre d'altres (Varley & Aughey, 2013). L'estrès fisiològic, psicològic i biomecànic resultant, descrit com a càrrega interna, impulsa la resposta d'adaptació del jugador (Vanrenterghem et al., 2017). El resultat de qualsevol intervenció d'entrenament és, per tant, la conseqüència tant de la càrrega externa com de la càrrega interna, per tant, les eines de seguiment són crucials per a l'optimització del rendiment físic (Impellizzeri et al., 2019) i per a una millor comprensió dels factors que afecten tant el rendiment físic com la recuperació. Per exemple, la divergència de càrrega externa i interna pot ajudar a diferenciar entre un esportista fatigat d’un esportista no fatigat (Thorpe et al., 2017).

Per tant, és acceptat i demostrat que els jugadors han de poder rebre un estímul adient mitjançant una periodització optima de les activitats realitzades, permetent una recuperació correcte entre episodis d’entrenament i competició per aconseguir les adaptacions fisiològiques desitjades del sistema (Vanrenterghem et al., 2017). També el registre de la càrrega externa i interna permet un control potencialment substitutiu de mesures de la càrrega mecànica. Aquestes mesures, mitjançant altres paràmetres complementaris com la intensitat, la repetició, l’estrès o el temps d’exposició, permeten crear models d’estimació de la resposta del sistema a l’estímul d’entrenament proposat (Kalkhoven et al., 2021). El control i avaluació de les demandes físiques imposades doncs, passa a ser de vital importància en contextos d’alt rendiment, ja que l’objectiu principal de preparadors físics i entrenadors és aconseguir trobar aquella mínima dosi optima que permeti trobar l’equilibri entre optimitzar el rendiment (ja sigui mantenint-lo o augmentant-lo) i no provocar un augment del risc de lesions.

Els conceptes de càrrega externa i càrrega interna van ser proposats per primer cop al vuitè *Annual Congress of the European College of Sport Science* a Salzburg, Àustria l’any 2003 (Impellizzeri et al., 2019). Franco Impellizzeri, va ser el pioner en la descripció de la taxonomia dels estímuls de l’entrenament amb dos articles (Impellizzeri et al., 2004, 2005) que per primer cop van usar els conceptes de càrrega externa i interna sobretot en el context dels esports d’equip. A continuació, ja que la investigació realitzada comporta l’anàlisi de les demandes físiques, per tant de les càrregues imposades a jugadors d’hoquei patins, es descriuen els dos tipus de càrregues citades (Figura 3).

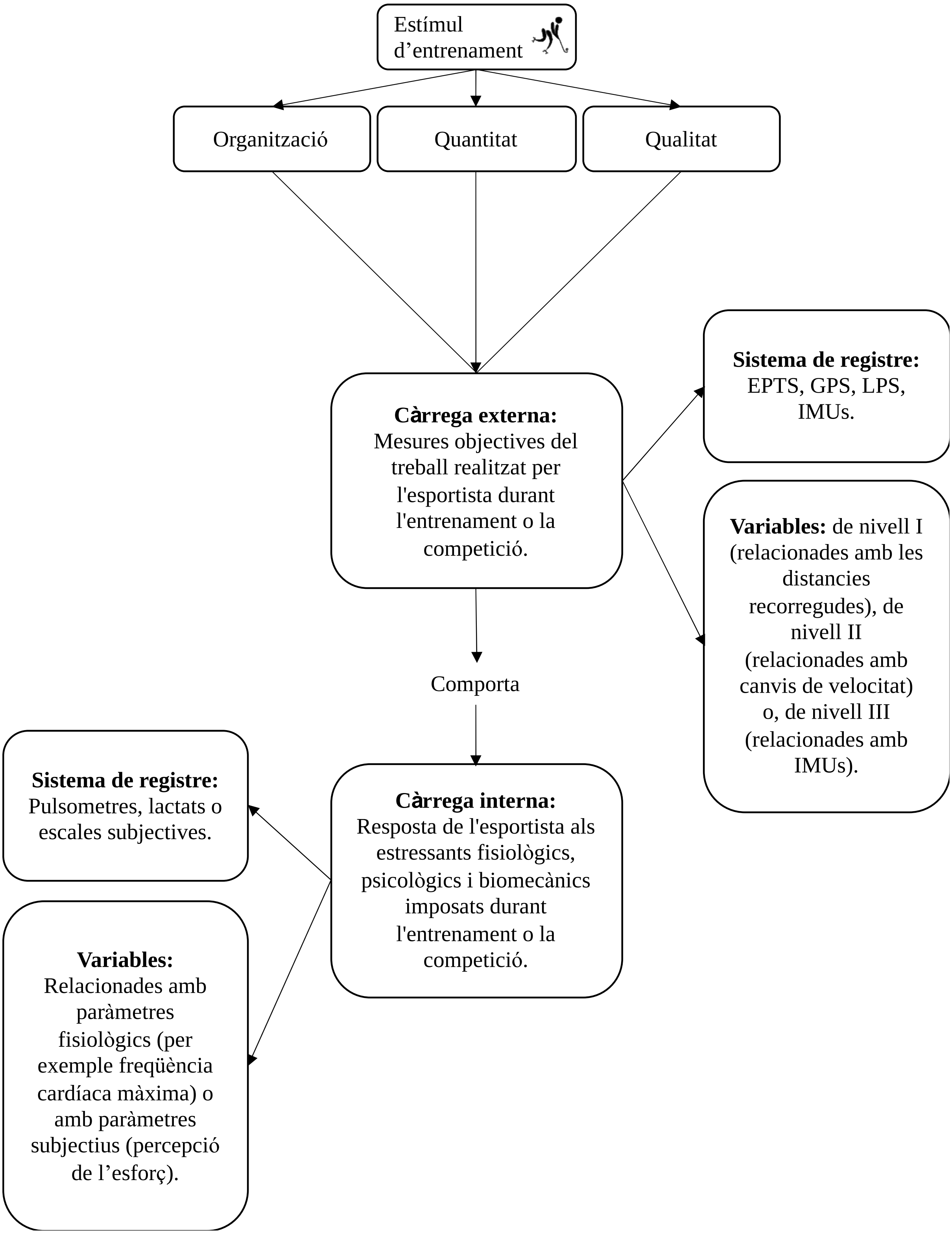


*Figura 3. Esquema representatiu del marc teòric descriptiu dels conceptes de càrrega externa i càrrega interna.*

### 2.2.1. Càrrega externa

L'organització, quantitat i qualitat de l'exercici proposat en qualsevol pla d'entrenament o que pot ocórrer en competició és el que determina la càrrega externa (Impellizzeri et al., 2005). També es pot definir la càrrega externa com el treball realitzat per un atleta, mesurat d'una forma independent a les seves característiques intrínseques (Wallace et al., 2009). En conseqüència, doncs, la mesura i quantificació d'aquesta càrrega externa és especifica a la naturalesa del entrenament o competició realitzada. Per exemple, la càrrega externa en l'entrenament de força, pot ser descrita com el pes mogut durant una sessió o un exercici (en Kg); també pot ser descrita com el treball completat (en W) o la velocitat mitjana en un exercici en concret (en m/s). La mateixa càrrega externa mesurada en la pista d'un esport d'equip pot ser descrita com la distancia total recorreguda (en m), nombre d'acceleracions o desacceleracions, o nombre d'esforços a més d'una velocitat llindar marcada.

El control de la càrrega externa és bàsic per entendre tant les demandes físiques que els entrenadors volen proposar als atletes en una sessió d'entrenament. Aquest control sovint descrit de forma molt detallada en esports individuals (per exemple: 400 m, 3 x 2000 m, o 42 km) a estat a la vegada molt difícil d'aconseguir en esports col·lectius. Sense una avaluació de la càrrega externa doncs, és impossible saber de forma objectiva el treball realitzat durant un entrenament o partit. El recent desenvolupament de micro-tecnologia permet un coneixement més detallat de la càrrega externa imposada als jugadors (Torres-Ronda et al., 2022). Per a la mesura d'aquesta càrrega externa doncs existeixen diferents mètodes de registre, diferents variables i diferents tècniques d'anàlisis amb les seves corresponents aplicacions. A continuació les descrivim.

#### *2.2.1.1. Sistemes de registre*

Existeixen diferents sistemes de registre que ajuden a mesurar la càrrega externa, entre altres: potenciòmetres; velocímetres; acceleròmetres; vídeo anàlisis o; sistemes electrònics de seguiment del rendiment (EPTS), dins d'aquests: sistemes de posicionament global (GPS), sistemes de posicionament local (LPS), sistemes inercials (IMU) i, la combinació dels anteriors. En el següent apartat els desgranarem per entendre el funcionament d'aquests i com ajuden a la mesura de la càrrega externa.

En esports col·lectius, l'ús de l'anàlisi del moviment també conegut com "*time-motion analysis*", és actualment la forma més habitual de controlar la càrrega externa. Ja sigui mitjançant l'ús de EPTS o l'ús de càmeres que de forma automàtica detecten i capturen el moviment dels jugadors. De forma més concreta, podem separar els sistemes de registre de la càrrega externa en esports col·lectius de tres formes diferents (Rico-González et al., 2020): sistemes de registre GPS, sistemes de registre LPS i sistemes de registre que utilitzen videografia digital. Aquests tres sistemes són complementats per sistemes IMU, els quals aporten informació complementaria als sistemes citats. Cada un dels diferents sistemes comporta uns avantatges i desavantatges diferents degut a la manera com registren el moviment, a continuació detallem les característiques dels sistemes utilitzats durant la tesis:

- Els sistemes de registre LPS son sistemes desenvolupats més recentment que els sistemes GPS. Aquests sistemes neixen donant resposta a la necessitat de trobar una tecnologia que pugui mesurar la posició i el moviment en interiors. Els sistemes LPS es poden classificar en sistemes de infrarojos, sistemes de radiofreqüència (dins d'aquests sistemes es pot usar tecnologia *Wi-Fi*, *Bluetooth* o banda ultra ampla [UWB]) i sistemes d'ultrasons. Entre els diferents tipus de sistemes LPS, el UWB és una tecnologia prometedora per al posicionament en interiors i també per a llocs exteriors on no hi ha possibilitat que la infraestructura circumdant interfereixi en els resultats. Igual que els sistemes GPS, l'ús d'una senyal que viatgi entre emissor, antena i receptor permet triangular la senyal i posicionar el sensor UWB en unes coordenades concretes. Els sistemes de registre LPS tenen dos avantatges clars respecte els sistemes GPS. En primer lloc els sistemes LPS poden funcionar a qualsevol lloc on s'instal·lin antenes, i en segon lloc els sistemes LPS al no enviar la senyal fins a satèl·lits, gaudeixen d'un menor marge d'error (sovint parlarem de centímetres, comparat amb metres d'error en sensors GPS). Literatura recent (Waqar et al., 2021) ha pogut demostrar que els sistemes de registre LPS son 40 cops més precisos que un sensor GPS a 1 Hz o 36 cops més precisos que un sensor GPS a 10 Hz. Actualment la limitació més important dels sistemes LPS que utilitzen tecnologia UWB, és el decreixement de la precisió del posicionament a mesura que el sensor s'aproxima als límits del sistema creat per les antenes (Waqar et al., 2021).

- Els IMU són una combinació de diferents sensors que recullen dades de moviment que es poden utilitzar per calcular aproximacions de treball, velocitat i fins i tot, angles de moviment. La combinació més corrent en un sistema IMU mescla 3 sensors diferents: acceleròmetres, giroscopis i magnetòmetres. Tots els sensors citats, no depenen de connexions a satèl·lits ni antenes, registren i guarden tota la informació de forma interna de forma molt eficient, per això tenen una freqüència de mostreig molt alta (de 100 a 1000 Hz). Els acceleròmetres mesuren els canvis en la velocitat de forma tant precisa i sensible que en realitat permeten detectar qualsevol petita tremolor a la que el sensor sigui exposada; els giroscopis mesuren l'orientació del sensor i permeten detectar els canvis d'aquesta orientació; finalment els magnetòmetres permeten orientar la direcció del sensor, permeten saber cap on està encarat aquest en tot moment. Els IMUs funcionen com a complements per als diferents sistemes de registre de la càrrega externa, ja que no son capaços de detectar posicionament en un camp o pista esportiva, i per tant, tenen limitacions per ells sols. Combinats amb dades de posicionament les dades extretes d'aquests sensors però, adquireix una nova dimensió ja que aporta informació extra que el posicionament solament no pot donar.

#### *2.2.1.2. Variables*

Per altra banda, a part dels sistemes de registre, és interessant saber quines variables s'utilitzen en l'anàlisi de la càrrega externa. Una de les classificacions més utilitzades és la classificació de Gray (Buchheit & Simpson, 2017), on les dades extretes del control de la càrrega externa poden agrupar-se en diferents categories (Taula 1).

*Taula 1. Categories de variables de càrrega.*

| Nivell | Descripció | Sensor | Exemple |
|---|---|---|---|
| 1 | Variables relacionades amb la distancia recorreguda | GPS / LPS | Distancia recorreguda > 18km/h |
| 2 | Tots els esdeveniments relacionats amb els canvis de velocitat: acceleracions, desacceleracions i canvis de direcció | GPS / LPS | Nombre d'acceleracions > $2m/s^2$ |
| 3 | Totes les mètriques derivades dels sensors IMUs | IMUS | Nombre d'impactes a > 8G |

Nota. Referencia adaptada de Buchheit & Simpson (2017)

Per tant, les variables de nivell 1 són totes aquelles relacionades amb les dades resultants derivades del posicionament de sistemes GPS o LPS. Son variables que poden anar des de la distancia recorreguda (utilitzant tant sols el posicionament), fins a velocitats mitjanes, i finalment distancies recorregudes en diferents zones de velocitat ja siguin absolutes com relatives als atletes, per exemple: distancia recorreguda entre 18 i 21 km/h o distancia recorreguda entre el 75% i 85% de la velocitat màxima de l'atleta.

Les variables de nivell 2 tenen relació amb els canvis de velocitat, per tant son variables que venen derivades de la velocitat dels atletes. Les acceleracions i desacceleracions són l'exemple més clar d'aquests tipus de mètriques. Poden comptar-se de formes diferents: per nombre de repeticions, per distancia recorreguda accelerant o desaccelerant, o per temps accelerant o desaccelerant; i també poden utilitzar-se llindars de diferents intensitats tant absoluts com relatius, per exemple: nombre d'acceleracions entre 2 i 4 $m/s^2$ o distancia recorreguda desaccelerant a més del 75% de la desacceleració màxima de l'atleta.

Per acabar, les variables de nivell 3 són variables que provenen de sensors existents en els sistemes EPTS que no son els sensors de posicionament. Acceleròmetre, giroscopis o magnetòmetres entre d'altres. Un dels exemples més clars d'aquest tipus de variables és el *player load*, una variable provinent dels acceleròmetres i que consisteix en la magnitud vectorial derivada dels tres eixos de l'acceleròmetre expressada en unitats arbitraries. Aquesta variable en concret ha estat calculada de diferents formes per les diferents marques comercials que fabriquen EPTS, des de la seva publicació per primer cop l'any 2010 (Montgomery et al., 2010).

#### *2.2.1.3. Tècniques d'anàlisi*

Una part important del control de la càrrega és "què i com" es tracten les dades extretes dels sistemes de registre. En aquest sentit, les demandes de la càrrega externa poden ser analitzades de moltes formes diferents: valors mitjans, valors màxims o mínims, llindars, escenaris de màxima o sub-màxima exigència, comparacions intra-jugadors, comparacions entre jugadors, o ratios entre variables. Per comprendre quines d'aquestes pràctiques son les més habituals en el tractament de dades de càrrega externa, i desprès explicar com s'ha tractat les dades durant la recerca realitzada, aquest apartat intenta descriure el tractament bàsic d'aquestes.

Sovint, l'anàlisi comença amb una descripció simple tant per entrenaments o partits, com per tasques, utilitzant les dades de nivell 1 i 2. Aquesta primera aproximació tan sols demanda de l'ús de mitjanes i desviacions estàndard per poder analitzar dades de tot l'equip, i potser ni aquests càlculs, si les dades es visualitzen de forma individual. Un pas més en aquest anàlisi, és posar en context les dades, comparant cada jugador amb ell mateix durant la resta de partits o entrenaments registrats. Per fer això, cal utilitzar mitjanes i desviacions estàndard, però també es poden fer servir unitats tipificades per així poder veure quantes desviacions estàndard varia un entrenament o partit d'una sèrie d'entrenaments o partits. Com es podrà comprovar a mesura que el lector avanci en aquesta tesis, el primer i segon article presentats utilitzen aquests tipus d'anàlisis per poder obtenir dades que contextualitzin partits i entrenaments.

Una altra pràctica utilitzada per l'anàlisi de la càrrega externa consisteix en l'ús de divisions per crear ràtios: ja sigui entre variables de nivell 1 o 2 durant diferents finestres temporals, conegut com a ràtio agut:crònic (Gabbett, 2016); o divisions entre diferents variables per obtenir valors relatius o valors d'eficiència. En el primer cas, la creació de ràtios s'obté dividint la mitjana de qualsevol variable de càrrega externa d'un període de temps relativament curt (3, 7 o 14 dies), anomenada càrrega aguda; entre la mitjana d'un període de temps relativament llarg (14, 21 o 28 dies), anomenada càrrega crònica. D'aquesta forma, s'obté un ràtio que permet obtenir informació sobre si la càrrega aguda està per sobre o per sota de la càrrega a la que està habituat l'atleta. Aquest anàlisis, no exclòs de polèmica (Impellizzeri et al., 2020, 2021), va suposar estudis que relacionaven aquest ràtio i les lesions en esports com futbol australià i futbol (S. Malone et al., 2017; Murray et al., 2017). En el segon cas comentat prèviament, els ràtios permeten la creació de noves variables creant així índex de eficàcia o eficiència. Aquests ràtios poden ser en format temporal, és a dir dividint variables de càrrega externa entre temps, per d'aquesta forma poder comparar variables sense tenir en compte la durada total del que s'ha registrat (tasca, entrenament o partit) creant noves variables de càrrega externa com ara metres/min, acceleracions/min o desacceleracions/min. Per altra banda, els ràtios també poden ser entre dos variables de càrrega externa (Lacome et al., 2018) que desemboquen en variables noves que descriuen valors d'eficiència; un exemple són les investigacions sobre variables que combinen variables de càrrega externa de nivell 1 o 2 registrada amb posicionament (metres/minut) i variables de càrrega externa de nivell 3 registrades amb acceleròmetre per poder descriure l'eficiència de la carrera o detectar una possible fatiga neuromuscular (Buchheit et al., 2018).

Totes les tècniques d'anàlisis descrites fins ara tenen relació amb valors mitjans o totals d'una tasca, d'un partit o d'un entrenament. Existeix evidencia científica (Martín Garcia et al., 2019;

Martín-García, Casamichana, et al., 2018) que demostra que aquests tipus d'anàlisi subestima les demandes reals a les que els atletes s'enfronten durant la competició o entrenament ja que els esports intermitents tenen fases de molta més intensitat que la que podem mesurar amb dades mitjanes. Per solucionar això, l'ús de mitjanes mòbils permet no subestimar intensitats que poden ser passades per alt en l'anàlisi tradicional. Aquestes mitjanes mòbils o *rolling averages* serveixen per descriure les demandes que comporten els anomenats escenaris de màxima exigència, o també *most demanding scenarios* (Vázquez-Guerrero & Garcia, 2021), *most demanding passages* (Salazar & Castellano, 2019) o *peak demands* (Alonso et al., 2020). La tècnica de mitjanes mòbils permet un anàlisi i descripció més vàlida respecte els moments on les demandes condicionals són més altes. Per fer-ho s'utilitzen finestres temporals preestablertes (per exemple 30, 60 o 120 segons). El valor obtingut durant la finestra temporal preestablerta de forma instantània cada vegada que el sensor fa una mesura, permet saber per exemple, quins han estat els 30 segons més demandants. Aquest tipus d'anàlisi s'ha emprat en altres esports com ara basquet (Fox et al., 2021; Vázquez-Guerrero et al., 2020; Vázquez-Guerrero & Garcia, 2021), on s'ha pogut demostrar que la diferencia entre les demandes mitjanes i els escenaris de màxima exigència d'un minut van des d'un percentatge de diferencia de 113,1% en distancia recorreguda a 686,4% en la distancia recorreguda a més de 18 km/h. Per tant, la utilització de demandes mitjanes podria comportar una infravaloració de les demandes físiques que comporta la competició i/o l'entrenament, provocant així una inadequada preparació dels jugadors per suportar aquests escenaris que existeixen durant els partits però que no es poden mesurar amb les tècniques d'anàlisi tradicionals.

Els escenaris de màxima exigència prèviament citats han estat àmpliament estudiats, però tan sols permeten l'anàlisi d'un sòl escenari per partit o entrenament. Aquest enfocament, tot hi ser més concret que l'anàlisi tradicional, no reflecteix el total d'exigències condicionals que es produeixen en un partit. Per exemple, podria ser que existís un escenari de màxima exigència de 140 metres en 30 segons i un altre escenari de 139 metres en un partit. Per tant, l'anàlisi d'escenaris de màxima exigència mostra tan sols el pic de demandes de qualsevol esdeveniment analitzat. A la vegada, és igual d'interessant saber la repetibilitat i/o la intensitat d'aquests escenaris propers al màxim. Per fer-ho, el mètode més repetit a la literatura (Caro et al., 2022; Johnston et al., 2022; Riboli et al., 2022; Thornton et al., 2020) consisteix en registrar els escenaris de màxima exigència individuals i trobar el valor de referencia individual (pot ser la mitjana de tots, el valor màxim, la mitjana dels 3 valors més alts...), per desprès analitzar la resta de partits o entrenaments en funció d'aquest valor. Fins ara, cap estudi però, ha descrit la distribució de diferents escenaris d'intensitat relativa en l'hoquei patins.

### 2.2.2. Càrrega interna

Independentment dels instruments, variables i tècniques d'anàlisi utilitzades per mesurar-la; entrenadors i preparadors físics prescrivim l'entrenament segons una càrrega externa determinada per tal d'obtenir una resposta psico-fisiològica desitjada. Les mesures de càrrega interna, en conseqüència, son els indicadors que reflecteixen la resposta psico-fisiològica real que el cos inicia per fer front als requeriments provocats per la càrrega externa imposada. Com la càrrega externa, no existeix una mesura correcte o incorrecte de la càrrega interna, sinó que aquesta es pot mesurar de moltes formes diferents depenent del context. Per exemple, la freqüència cardíaca pot ser una mesura valida de la càrrega interna en esports de resistència però incorrecte en esports de força. Fins i tot, en el mateix context, la mateixa variable de càrrega interna pot no tenir la mateixa validesa: la freqüència cardíaca pot ser un indicador poc vàlid en esforços intermitents d'alta intensitat i per contra un bon indicador en esforços de llarga durada.

A continuació descrivim els diferents sistemes de registre i variables que es poden utilitzar per la monitorització de la càrrega interna en el context dels esports d'equip.

#### *2.2.2.1. Sistemes de registre*

Com ja s'ha descrit en el cas de la carrega externa, en el cas del control de la carrega interna, existeixen diferents mètodes de registre. Podem diferenciar aquests mètodes en dos grans grups que ens permetran classificar els diferents sistemes de registre: per una banda els subjectius i per altra banda els objectius.

Els sistemes de registre de càrrega interna subjectius es composen bàsicament d'escales de percepció de l'esforç (RPE). Malgrat que els estudis publicats sobre la validesa de les mesures subjectives en entorns d'esports d'equip són limitats, s'ha observat que l'escala de RPE de Borg (Foster et al., 2001) és la mesura de càrrega interna més comuna tant en investigació com en el terreny pràctic. Això es deu principalment a la seva facilitat de recollida, a la seva despesa insignificant i a la seva capacitat per quantificar les càrregues en totes les formes d'entrenament existents (entrenament de camp, entrenament de força, o rehabilitació, etc...) i en competició.

La multiplicació del valor del RPE per la duració de l'entrenament ofereix un altre mètrica de registre anomenada percepció de l'esforç de la sessió (sRPE). Tant el RPE com el sRPE són dos sistemes de registre de càrrega interna subjectius utilitzats en algun dels articles que conformen aquesta tesi i àmpliament emprats en el context dels esports col·lectius (Haddad et al., 2017).

Els sistemes de registre de càrrega interna objectius tenen a veure amb el registre de la freqüència cardíaca, TRIMPS, lactats o consum d'oxigen, entre d'altres. El registre de la freqüència cardíaca (i posteriorment la utilització dels TRIMPS, que provenen també del registre de la freqüència cardíaca) és el mètode més utilitzat en els esports d'equip degut a la facilitat respecte altres mètodes citats (Schneider et al., 2018). La mètrica més emprada a part del propi registre de la freqüència cardíaca és la freqüència cardíaca màxima ja que és necessària per poder expressar les dades registrades en valors relatius al màxim de l'atleta. Aquesta mètrica tant bàsica pot extreure's d'un test maximal en laboratori (normalment sobre cinta de córrer o pista d'atletisme), o en esports d'equip s'ha comprovat que també pot utilitzar-se el registre diari durant entrenaments i competicions per buscar el valor màxim registrat i fer-lo servir com a freqüència cardíaca màxima individual (Abad et al., 2016).

#### *2.2.2.2. Variables*

Durant la monitorització de la càrrega interna els diferents mètodes de registre emanen diferents variables que es poden utilitzar. Per una banda, tant el RPE com el sRPE anteriorment citats són mètriques registrades en unitats arbitraries i com ja hem explicat, subjectives. Per altra banda, el registre de la freqüència cardíaca comporta l'anàlisi de diferents variables. Una de les més utilitzades és la freqüència cardíaca mitjana i/o màxima (tant absoluta com relativa al màxim individual) durant l'exercici analitzat; també l'ús del temps o percentatge del temps registrat en diferents zones de freqüència cardíaca relativa són variables utilitzades en la recerca de la càrrega interna, per exemple: segons registrats entre el 70% i 80% de la freqüència cardíaca màxima.

# 3. Objectius

L'objectiu general és caracteritzar i contextualitzar les demandes de càrrega externa i interna de la competició i entrenament d'hoquei patins d'elit. Per poder assolir i respondre a aquest objectiu, hem designat i dividit una sèrie d'objectius específics en els diferents articles de la tesi:

- Quantificar i determinar la càrrega externa que comporta un partit oficial d'hoquei patins, i comprovar si existeixen diferencies entre posicions (estudi 1).
- Analitzar com es relaciona i evoluciona la càrrega externa i interna d'entrenament respecte el dia de partit durant una setmana d'entrenament (estudi 2).
- Quantificar i determinar la càrrega externa dels escenaris de màxima exigència i comprovar si existeixen diferencies entre posicions (estudi 3).
- Consolidar l'ús i quantificar la repetició d'escenaris de diferents intensitats en partits oficials i comprovar si existeixen diferencies entre posicions (estudi 3).
- Comparar la càrrega externa i interna d'un partit d'entrenament (40 x 20 m.) i un joc reduït (20 x 20 m.) (estudi 4).

Per altra banda, les hipòtesis d'aquesta tesi són:

- La càrrega externa és independent de les posicions de joc en partits d'hoquei patins (estudi 1).
- Els entrenaments amb la càrrega externa i interna més elevada són els més allunyats del partit oficial durant la setmana d'entrenament (estudi 2).
- Els escenaris de màxima exigència comporten exigències similars per les diferents posicions en partits d'hoquei patins (estudi 3).
- La repetició d'escenaris de diferents intensitats en partits oficials és independent de les posicions de joc en partits oficials d'hoquei patins (estudi 3).
- La reducció de l'espai de joc en situacions de partit fa que hi hagi menys càrrega interna i menys càrrega externa (estudi 4).

# Capítol 2.

# Mètodes

Aquesta tesi té una part experimental formada per quatre estudis que comparteixen trets comuns i a la vegada, cada un d'ells, té les seves particularitats en quant a la metodologia utilitzada. A continuació descriurem la metodologia emprada en cada un d'ells.

# 4. Dissenys experimentals i participants

Els quatre estudis tenen dissenys experimentals semblants: són observacionals, descriptius i retrospectius. Totes les dades van ser extretes durant entrenaments i partits del primer equip masculí sènior d'hoquei patins del Futbol Club Barcelona. Els processos experimentals van ser aprovats pel comitè d'ètica d'investigació clínica del Consell Català de l'Esport (29/CEICGC/2020), i van proporcionar per escrit el seu consentiment informat per participar en els estudis. Cada un però, ha estat realitzat amb mostres de participants, moments temporals i particularitats diferents.

## 4.1. Estudi 1

Utilitzant un sistema EPTS es van monitoritzar partits de la temporada 2017/2018 (concretament del setembre del 2017 a febrer del 2018). Un total de nou partits van ser inclosos en l'anàlisi amb un total de 63 observacions individuals. Vuit jugadors (edat: 29,6 ± 5 anys; pes: 78,1 ± 4,6 kg; alçada: 178,8 ± 3,1 cm) van participar en l'estudi de forma voluntària. Es van descartar els porters i tots aquells jugadors que no acabessin els partits analitzats o que no haguessin entrenat durant la totalitat de la sessió d'entrenament pre-partit. Es van categoritzar els jugadors analitzats en dos posicions: exteriors (n=6) i interiors (n=2). Es van comparar les demandes mitjanes de càrrega externa entre posicions durant partits oficials.

## 4.2. Estudi 2

Durant les temporades 2018/2019 i 2019/2020 (la temporada 2019/2020 tan sols fins el març degut a la pandèmia de COVID-19) es van monitoritzar totes les sessions d'entrenament i partits mitjançant l'ús d'un sistema EPTS. Es van analitzar un total de 23 setmanes d'entrenament de 75 possibles ja que tan sols van ser seleccionades aquelles setmanes que tenien 1 sol partit durant el cap de setmana, que tenien 4 sessions prèvies al partit, que tenien com a mínim un dia de descans respecte l'últim partit jugat i que el partit era oficial. Nou jugadors (edat 29,8 ± 5,77 anys, pes: 79,5 ± 5,50 kg, alçada 180,4 ± 4,03 cm) van participar a l’estudi de forma voluntària. En aquest estudi no es van categoritzar els jugadors per posicions. Un total de 82 sessions entre entrenaments i partits van ser registrades. Es van comparar les demandes de càrrega externa i interna durant els diferents dies de sessió d’entrenament i partit. Les dades de càrrega dels entrenament es van analitzar pel que fa al nombre de dies abans del partit que van ser: dia del partit (DP) menys Z dies. Per exemple, DP-2 van ser les sessions d’entrenament dos dies abans de partit.

### 4.3. Estudi 3

Es van monitoritzar 18 partits mitjançant un sistema EPTS durant les temporades 2019/2020 i 2020/2021 (la temporada 2019/2020 fins el març degut a la pandèmia de COVID-19). Voluntàriament nou jugadors (edat: 29,0 ± 5,22 anys; pes: 78,8 ± 6,20 kg; alçada: 180,6 ± 3,91 cm) van participar en l’estudi. Els porters no es van incloure, i tots aquells jugadors que no acabessin els partits registrats o que no haguessin entrenat durant la totalitat de la sessió d’entrenament pre-partit. Com en el primer estudi, es van categoritzar els jugadors en dos posicions: exteriors (n=7) i interiors (n=2). Es van comparar els escenaris de màxima exigència i la repetició d’escenaris de diferents intensitats entre posicions durant partits oficials.

### 4.4. Estudi 4

La temporada 2020/2021 es van monitoritzar totes les sessions d’entrenament durant 17 setmanes de temporada utilitzant un sistema EPTS i de registre de freqüència cardíaca. De les sessions d’entrenament, tan sols es van analitzar dos tipus de tasca per comparar-les entre elles. Vuit jugadors (edat: 28,5 ± 5,07 anys; pes: 78,6 ± 4,13 kg; alçada: 180,8 ± 4,13 cm) van ser inclosos en l’estudi sense categoritzar-los per posicions. Els porters es van excloure de l’anàlisi. Un total de 371 observacions individuals van ser incloses en l’anàlisi. Es van comparar les demandes de càrrega externa i interna mitjanes durant dos tasques d’entrenament de diferent espai de joc.

## 5. Procediments

El registre de dades per avaluar la càrrega externa es va realitzar amb un sistema LPS (WIMU PRO™, Realtrack Systems SL) i el seu programari corresponent (SPRO™, Realtrack Systems SL, versió 962). Els dispositius es van col·locar a la part superior de l'esquena utilitzant un arnes ajustat. El sistema WIMU PRO™ inclou quatre acceleròmetres de tres dimensions (els rangs de sortida són ± 16 g, ± 16 g, ± 32 g, ± 400 g i la freqüència de mostreig de 100 Hz), tres giroscopis (sortida a un rang 8000 °/s, freqüència de mostreig de 100 Hz), un magnetòmetre 3D (freqüència de mostreig de 100 Hz), un sensor GPS (freqüència de mostreig de 10 Hz) i uns sensor LPS de tecnologia UWB (freqüència de mostra de 18 Hz). El sistema UWB es va instal·lar a la pista de la següent manera: es van col·locar sis antenes amb tecnologia UWB a 5 metres de la línia perimetral de la pista. El sistema WIMU PRO™ va presentar un alt valor de coeficient de correlació intraclasse per a la coordenada x (0,65), un valor molt alt per a la coordenada y (0,85) i un bon percentatge d'error tècnic de mesura: 2 (Bastida Castillo et al., 2019).

Totes les sessions d’entrenament i partits van ser registrats a la mateixa pista durant tots els estudis realitzats sempre amb les mateixes condicions ambientals: temperatura similar, superfície de joc i dimensions de la pista. Tots els partits registrats van ser oficials i van començar amb un escalfament estàndard de 30 minuts per als jugadors. Tots els entrenaments registrats van ser entrenaments col·lectius sempre dins de temporada.

En la Taula 2, basada en el treball de García (2021), es pot observar un resum de les 5 variables analitzades i en quins estudis es van fer servir. Les variables escollides per descriure la carrega externa van ser les mateixes durant tots els estudis, depenent del cas en valors absoluts o en valors relatius al minut. Per relativitzar les variables, es va dividir els valors registrats de càrrega externa entre els minuts que els jugadors estaven a pista, excloent així parades per hidratar-se durant l’entrenament, temps d’explicació enter tasques, o també totes les estones que els jugadors passaven fora de pista durant un partit. En concret es va mesurar: distància recorreguda en metres (DT; m); patinatge d'alta velocitat o distància recorreguda per sobre de 18 km/h en metres (HSS >18 km·h$^{-1}$; m); Player Load, una magnitud vectorial expressada com l'arrel quadrada de la suma de les velocitats instantànies quadrades del canvi de l'acceleració en cadascun dels tres plans que mesura l’acceleròmetre dividida per 100 en unitats arbitràries (PL; AU); nombre d'acceleracions d'alta intensitat (ACC; >2 m·s$^{-2}$; n) i nombre de desacceleracions d'alta intensitat (DEC; >2 $m \cdot s^{-2}$; n). Totes aquestes variables es van escollir per dos motius: en primer lloc, han estat les més utilitzades en altres estudis descriptius de càrregues de competició en la investigació d'esports d'interior, i els llindars utilitzats han estat també els més comuns en la bibliografia analitzada (García et al., 2020; Vázquez Guerrero, Reche Royo, et al., 2018; Vázquez-Guerrero et al., 2019); en segon lloc, aquest és un punt de partida en aquest tipus de literatura per a més investigacions tant sobre variables com sobre llindars en l'hoquei patins degut a la poca bibliografia existent.

Les variables escollides per l'anàlisi de la càrrega interna depenent de l'estudi van ser: el RPE, el sRPE i la freqüència cardíaca. Més concretament, en els estudis que es va mesurar la càrrega interna utilitzant el RPE i el sRPE, es va recollir l'esforç percebut de cada jugador aproximadament 30 minuts després de cada sessió d'entrenament o partit específic a la pista utilitzant l'escala d'esforç percebut de Borg de 0 a 10 punts modificada per Foster et al. (2001 falta bibliografia). Tots els jugadors estaven familiaritzats amb l'ús de l'escala ja que en l'equip el seu ús és comú i fa més d'una temporada que funciona. Es va utilitzar una aplicació per a telèfons intel·ligents per evitar el biaix i mantenir la subjectivitat en la resposta del jugador i la pregunta utilitzada va ser: "Com de dur ha estat la sessió d'avui?". Posteriorment, es va calcular el sRPE de la sessió específica a la pista multiplicant la durada específica de la sessió (o del joc) en minuts per les puntuacions individuals de RPE declarades per a l'entrenament (o joc) i es va presentar en unitats arbitràries (Foster et al., 2001). Per altra banda en els estudis que es va utilitzar la freqüència cardíaca, la variable registrada va ser el temps passat per sobre del 90% de la freqüència cardíaca màxima individual. Tant el RPE com el sRPE no es va relativitzar al minut per la pròpia naturalesa de la variable; per altra banda la freqüència cardíaca sí va calcular-se de forma relativa dividint el temps passat per sobre del 90% de la freqüència cardíaca entre el temps registrat.

*Taula 2. Descripció de les variables utilitzades per a l'anàlisi de les demandes físiques de càrrega externa i interna.*

| Variable | Abreviació | Sensor | Tipus | Estudi | Descripció |
|---|---|---|---|---|---|
| Distància recorreguda | DT | LPS | Càrrega externa | 1,2,3,4 | Distancia recorreguda > 0 $km \cdot h^{-1}$ |
| Distància recorreguda a alta velocitat | HSS | LPS | Càrrega externa | 1,2,3,4 | Distancia recorreguda > 18 $km \cdot h^{-1}$ |
| *Player Load* | PL | IMU | Càrrega externa | 1,2,3,4 | Magnitud vectorial derivada de l'acceleròmetre triaxial |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | expressada en unitats arbitràries |
| Acceleracions | ACC | LPS | Càrrega externa | 1,2,3,4 | Número d'acceleracions > 2 $m \cdot s^{-2}$ |
| Desacceleracions | DEC | LPS | Càrrega externa | 1,2,3,4 | Número de desacceleracions > 2 $m \cdot s^{-2}$ |
| Percepció de l'esforç | RPE | | Càrrega interna | 2 | Percepció de l'esforç percebut en l'escala de Borg de 0 a 10 punts |
| Percepció de l'esforç de la sessió | sRPE | EPTS | Càrrega interna | 2 | Percepció de l'esforç percebut per la durada de la sessió expressada en unitats arbitraries |
| Freqüència cardíaca | | EPTS | Càrrega interna | 4 | Temps > 90% de la freqüència cardíaca màxima expressat en segons |

Es va utilitzar l'anàlisi dels valors màxims de la mitjana mòbil durant finestres temporals de 30 segons per la quantificació dels escenaris de màxima exigència en els estudis que necessitaven aquest tipus de metodologia. L'elecció de la finestra temporal de 30 segons és deguda a la intermitència existent durant la competició en hoquei patins, on més del 70% de les accions realitzades entre pauses són de 30 segons o menys (Merino Tantiña et al., 2014).

Per l'anàlisi de la repetició d'escenaris de diferents intensitats en els estudis on es va utilitzar aquesta metodologia es va seguir el següent procediment. Es va determinar un valor de referència individual (valor de referència de l'escenari de màxima exigència individual que indica el 100%) a partir de la mitjana dels tres escenaris més alts registrats per jugador utilitzant la mostra amplia de partits. Un cop trobats els valors de referencia, es van tornar a analitzar tots els partits o entrenaments cercant tots els escenaris de 30 segons de totes les diferents intensitats existents (des de les màximes fins les més baixes), transformant els valors absoluts a relatius utilitzant els valors màxims de referència. Finalment es van comptar el nombre d'escenaris trobats en els diferents calaixos d'intensitat de 10% en 10%. El resultat final va ser el nombre total d'escenaris per cada calaix d'intensitat, per jugador i variable.

# 6. Estadística

Tots els anàlisis estadístics es van realitzar amb el programa RStudio i les versions 1.2.503 i 1.3.1093 (RStudio, Inc.). Els paquets estadístics que es van utilitzar van ser: *"readxls"*, *"tidyr", "dplyr", "ggridges", "plyr", "ggplot2", "scales", "viridis", "pipeR", "effsize", "bootES", "officier" i "rvg"*. Els resultats descriptius es van mostrar sempre com a mitjana ± desviació estàndard. Les dades analitzades de tots els estudis van fallar proves d'homogeneïtat de la variància (test de Levene) i la majoria de variables també van fallar les proves de normalitat (test de Shapiro-Wilk). Degut a aquestes característiques en tots els grups de dades analitzats, es va utilitzar majoritàriament (excepte en el primer estudi on es va utilitzar proves no paramètriques) el mètode de *bootstraping* en tots els estudis que conformen aquesta tesis (Tian, 2010) per comprovar si existien diferencies significatives entre grups. Més concretament, es va utilitzar un model de remostreig residual emprant entre 2000 i 10000 repeticions per calcular els intervals de confiança del 95% de les proves estadístiques necessàries en cada estudi. En tots els estudis, a part de calcular les diferencies de mitjanes també es van calcular les diferencies utilitzant la mida de l'efecte. Els llindars que es van utilitzar van ser (< 0,20), diferencies trivials; (0,20 < 0,59), diferencies petites; (0,60 < 1,19), diferencies moderades; (1,20 < 1,99), diferencies grans; i (> 2,0), diferencies molt grans (Hopkins et al., 2009). També es van realitzar proves de correlació quan van ser necessàries; els llindars que es van utilitzar van ser: trivial (< 0,1), petita (0,1 < 0,3), moderada (0,3 < 0,5), gran (0,5 < 0,7), molt gran (0,7 < 0,9), gairebé perfecte (> 0,9) o perfecte (= 1) (Hopkins, 2016).

# Capítol 3.

# Estudis i resultats

# 7. Estudi 1

Aquest estudi es correspon amb el següent article:

Quantification of external load of elite rink hockey players in official matches

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**ABSTRACT**

BACKGROUND: The demands of elite rink hockey competition are unknown to coaches, although nowadays the explosion of tracking technology makes it possible to fill this research gap. The aims of this study were twofold: firstly, to describe the external load demands involved in a rink hockey match, and secondly, to ascertain whether there were differences between exterior (EX) and interior or forward (IN) player positions.

METHODS: A retrospective observational study was conducted during the 2017-2018 competitive season. Eight professional players (6 EX and 2 IN) participated voluntarily in the study during 9 official matches. Data logging was performed with a local positioning system and the variables studied were distance covered (DT), distance covered above 18 km/h (HSS), player load (PL), number of high-intensity accelerations (ACC) and number of high-intensity decelerations (DEC).

RESULTS: The average values per player were 4,646 ± 1,135 m of DT for EX and 4,919 ± 1,374 for IN, 897 ± 252 m of HSS for EX and 981 ± 313 for IN (mean ± SD); 173 ± 69 and 167.5 ± 57.5 ACC for EX and IN, respectively, and 164 ± 56 and 152.5 ± 42 DEC for EX and IN, respectively (median ± IQR); and there were no significant differences ($p>0.05$), between positions.

CONCLUSIONS: The findings of this study allow us to ascertain the external load in matches and that EX and IN did not present different physical demands. With this information, coaches can adjust training loads more accurately.

***Keywords:*** Hockey; Athletic performance; Athletes

## INTRODUCTION

Rink hockey is a non-Olympic indoor team sport that is very popular in different countries such as Portugal, Italy, France, Argentina and Spain, among others. For example, in Catalonia it is the third team sport with most licenses after soccer and basketball[1]. It is played on a 40 x 20 m court between 2 teams of 5 players (four outfield players and a goalkeeper) and all the players use 4-wheel skates and a stick. As is common in other indoor team sports, there is an unlimited possibility of implementing changes between court and bench players. In 2009, the rules of play were changed to make it faster and more attractive to fans, thus leading to changes in the game models of teams and probably in competition requirements.

The bibliography that analyses the physical demands of the game[2,3] dates mostly from the 1990s (only one study about competition load is after the change of rules in 2009), when rink hockey was an exhibition sport at the Barcelona '92 Olympic Games and a very minor sport compared to other team sports such as soccer[4–6], basketball[7–10] or handball[11,12]. The only research into load in competition after 2009 presents data from video analyses of 6 matches during the 2012 Spanish King's Cup[3]. Some noteworthy results included the fact that between 70% and 71% of player movements were made at low (0 to 2.4 steps/s) or medium intensity (2.5 to 4.9 steps/s), while the remaining 29% were high-intensity movements (>4.9 steps/s). Of these high-intensity movements, 82% lasted between 1 and 5 seconds. However, with all the information presented in the study, we continue to be unaware of variables such as player total distance, accelerations and decelerations. Therefore, there is a major information gap in terms of the external load demands involved in competition in modern rink hockey matches, which signifies an important disadvantage when presenting the content and magnitude of loads during training.

Almost all the research in indoor team sports competitions had been conducted using video analysis, although recently the boom of GPS devices, coupled with their reliability[13], has made it easier to analyze both training and outdoor sports competition. Leveraging the improvements in local positioning such as Ultra-Wideband (UWB) technology[14,15] allows us to obtain valid and reliable data from on-court events. Variables such as total distance, number and duration of accelerations and decelerations, meters of high-speed running, player load, high metabolic load distance, sprints and other variables are much more readily available now and this information could be very valuable for strength and conditioning coaches and technical staff. Thus, the aims of this study were firstly to quantify the external load demands related to a rink hockey match and subsequently to verify whether there were differences between player positions.

## MATERIALS AND METHODS

A retrospective observational study was conducted during the 2017-2018 competitive season. The information on external load involved in a match was collected through a UWB positioning system (WIMU PRO™, Realtrack Systems, Almeria, Spain) during the official competition of a professional team of the highest Spanish male rink hockey category (Ok Liga) and which participated in the WSE Rink Hockey Euroleague. A non-experimental, descriptive method was used to identify the demands of rink hockey matches and the differences between positions. All the players of a professional rink hockey team (n=8) (age: 29.6 ± 5 years, weight: 78.1 ± 4.6 kg, height: 178.8 ± 3.1 cm) participated voluntarily in the study, while the goalkeepers were not included. In that season, 5 of the 8 players of the sample played for their respective national teams. There were two inclusion criteria: firstly, that players finish the match without injury and secondly that the players participated in the entire pre-match training session, thus ensuring the inclusion of only players who were prepared for the match the day before it was played. Of these 8 players, there were 6 exteriors (EX) and 2 interiors or forwards (IN). All the information was collected in the course of the 2017-2018 season, between September 2017 and February 2018. At the time of the study, the team was holding between 4 and 5 practice sessions a week and was playing 1 or 2 matches a week. The data analyzed stemmed from daily player monitoring, in which player activities are measured routinely in the course of the season. Therefore, the approval of an ethics committee was not required[16], although the study was conducted in accordance with the Declaration of Helsinki, and the players provided their informed consent before participating.

All matches recorded were official and began with a standard 30-minute warm-up for the players, and they were all played on the same court (always home) in the same environmental conditions. A total of 9 matches were included in the study and a total of 8 data files were saved for each match (if all the players met the aforementioned criteria), yielding a database that used 63 files. Whenever the players were not on the court they were excluded from the analysis. The mean duration and standard deviation of the time on court for EX was 40.3 ± 15.7 minutes and 39.09 ± 13.6 minutes for IN.

Data logging was performed with a local positioning system (WIMU PRO™, Realtrack Systems SL) and its corresponding software (SPRO™, Realtrack Systems SL, version 946). The devices were fitted to the upper back using tight harnesses. The WIMU PRO™ features four 3D accelerometers (full-scale out output ranges are ± 16 g, ± 16 g, ± 32 g, ± 400 g, 100 Hz sample frequency), three gyroscopes (8000º/s full-scale out output range, 100 Hz sample frequency) a 3D magnetometer (100 Hz sample frequency), a GPS (10 Hz sample frequency), a UWB (18 Hz sample frequency). The UWB system was installed on the court as follows: 4 antennae with UWB technology were placed 5 m from the perimeter line of the field. The WIMU PRO system presented better accuracy (bias: 0.5%7 - 5.85%), test-retest reliability (% technical error of measurement [% TEM]: 1.19) and inter-unit reliability (bias: 0.18) in determining distance than GPS technology (bias: 0.69-6.05%; % TEM: 1.47; bias: 0.25)[17]. More recently, the WIMU PRO system presented a high intra-class correlation coefficient (ICC) value for the x-coordinate (0.65), a very high value for the y-coordinate (0.85) and a good % TEM: 2.[18]

The following variables were calculated in absolute terms and per minute to describe the demands and to analyze the differences between positions: distance travelled in meters (DT; $m \cdot min^{-1}$); distance covered above 18 km/h in meters (HSS >18$km \cdot h^{-1}$; $m \cdot min^{-1}$); Player Load, vector magnitude, expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each of the 3 planes divided by 100 in arbitrary units (PL; $AU \cdot min^{-1}$); number of high-intensity accelerations (ACC; >2$m \cdot s^{-2}$; $n \cdot min^{-1}$) and number of high-intensity decelerations (DEC; >2m·s-2; $n \cdot min^{-1}$). All these variables were selected because they were the most commonly used ones in other descriptive studies of competition loads, and the thresholds used were the ones most emphasized in indoor sport research[19–22].

Data distribution was analyzed by the Shapiro-Wilk test and data homoscedasticity by the Levene test to check normal distribution. DT, HSS and PL presented normal distribution and equal variances. DT/min, HSS/min, ACC, ACC/min, DEC, DEC/min and PL/min did not present a normal distribution. The Student's t-test was used for normally distributed data. The Mann-Whitney U test was used for non-normally distributed data. The level of significance was defined as 0.05. The analysis for normally distributed data was presented as mean and standard deviation (SD) and for non-normally distributed data it was presented as the median and interquartile range (IQR)[23]. Cohen's d was calculated for normally distributed data, and threshold values were 0 - 0.2 trivial, 0.2 - 0.6 small, 0.6 - 1.2 moderate, 1.2 - 2.0 large and >2.0 very large[24].

## RESULTS

The variables studied are reported in Table 3 and Table 4, expressed in means or medians depending on the statistical analysis applied. The tables also show the inference tests where none of the variables analyzed returned significant differences between positions. Data points in all variables and data distribution are presented in Figure 4.

*Table 3. Descriptive, test and effect size statistics for parametric tests.*

| Outcome | G | n | Mean | Std. Dev. | df | t | p | Cohen's d |
|---|---|---|---|---|---|---|---|---|
| **DT (m)** | EX | 37 | 4,645.66 | 1,135.20 | 47.20 | -0.833 | 0.409 | 0.19 |
| | IN | 26 | 4,918.84 | 1,373.82 | | | | |
| **HSS (m)** | EX | 37 | 896.58 | 251.76 | 46.29 | -1.139 | 0.260 | 0.26 |
| | IN | 26 | 980.88 | 312.74 | | | | |
| **PL (AU)** | EX | 37 | 26.47 | 6.37 | 54.73 | 0.517 | 0.607 | 0.12 |
| | IN | 26 | 25.63 | 6.23 | | | | |

*Note. DT = Distance travelled, HSR = High-speed skating, PL = Player Load.*

*Table 4. Descriptive and test statistics for non-parametric tests.*

| Outcome | G | n | Median | IQR | U | z | p |
|---|---|---|---|---|---|---|---|
| **DT/min (m)** | EX | 37 | 129.72 | 21.15 | 446 | -0.489 | 0.625 |
| | IN | 26 | 132.14 | 23.65 | | | |
| **HSS/min (m)** | EX | 37 | 24.8 | 5.48 | 410 | -0.991 | 0.322 |
| | IN | 26 | 26.79 | 6.09 | | | |
| **ACC (n)** | EX | 37 | 173 | 69 | 466 | -0.209 | 0.834 |
| | IN | 26 | 167 | 57.5 | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **ACC/min (n)** | EX | 37 | 4.84 | 1.42 | 438 | -0.600 | 0.548 |
| | IN | 26 | 4.75 | 1.16 | | | |
| **DEC (n)** | EX | 37 | 164 | 56 | 407.5 | -1.026 | 0.305 |
| | IN | 26 | 152.5 | 42 | | | |
| **DEC/min (n)** | EX | 37 | 4.57 | 1.51 | 386.500 | -1.319 | 0.187 |
| | IN | 26 | 4.27 | 0.98 | | | |
| **PL/min (AU)** | EX | 37 | 0.72 | 0.17 | 371.500 | -1.530 | 0.126 |
| | IN | 26 | 0.70 | 0.08 | | | |

*Note. DT = Distance travelled, HSS = High-speed skating, ACC = High-intensity accelerations, DEC = High-intensity decelerations, PL = Player Load.*

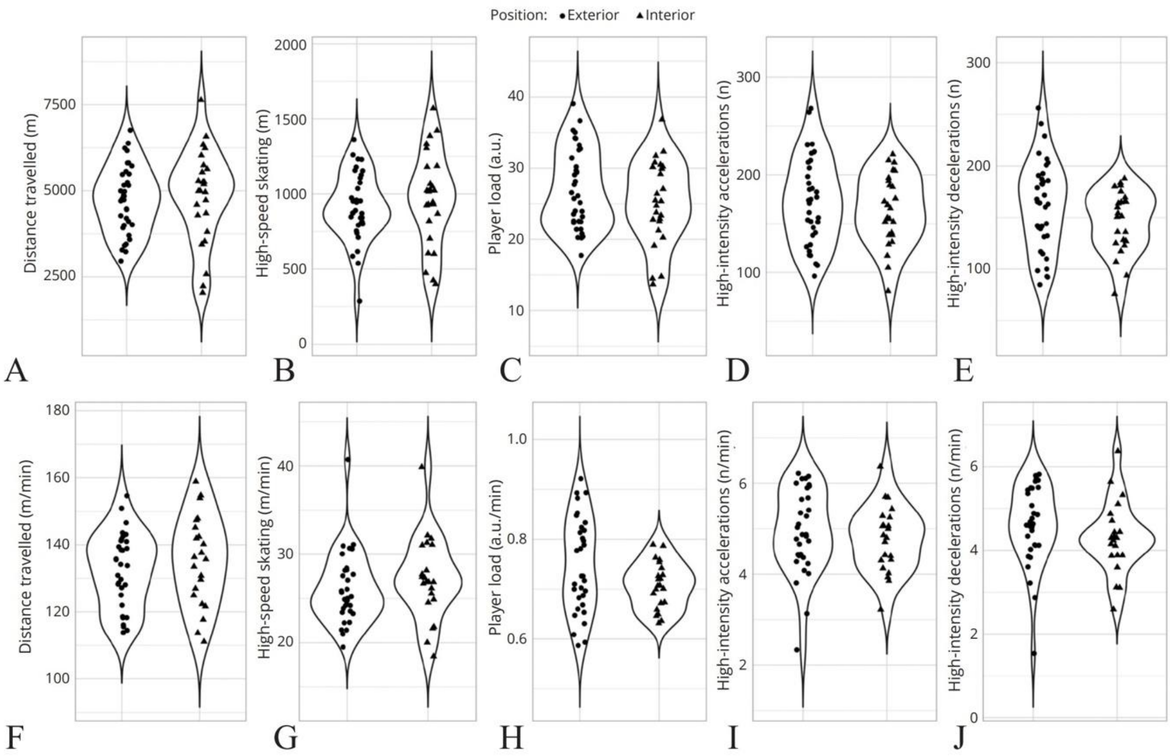


*Figure 4. Violin plot and data distribution for all variables.*

**DISCUSSION**

This is the first study to quantify the external load of elite rink hockey players in official competition and to examine whether there were differences between positions in the same scenario. The main findings of the investigation were that for the first time it was possible to describe the average external load demands of rink hockey game of an elite team and secondly that there were no differences between EX and IN in all the variables studied.

With regard to the first objective, due to the non-existence of publications that describe rink hockey external load competition demands through positioning technology, we were only able to compare our results with other research that used video recordings in the same sport or published papers that used local positioning systems in other indoor sports, regardless of player position. Furthermore, the small sample size, due to the very high level of the players analyzed, means that caution should be exercised when universalizing these results to other rink hockey teams, especially if they do not have the elite status.

Regarding external load competition demands, the DT data from this study place rink hockey clearly behind outdoor sports such as soccer[25,26] and rugby27. This is an expected outcome since, like other indoor sports, rink hockey has a smaller court area and a shorter match duration[28]. Moreover, the use of absolute distance values such as DT masks an important feature of indoor sports, namely continuous substitution policies. Therefore, the use of mean relative distance values (DT/min) rather than mean absolute values (DT) has been proposed as an appropriate tool for the comparison of external load volume metrics[29]. Then, the DT/min of the rink hockey team analyzed is higher than other indoor sports analyzed in the scientific literature such as Futsal[19,30], Handball[20] or Basketball[31]. Interestingly, this could be explained by the fact that the use of skates in rink hockey makes it easy to move around the court and more difficult to remain motionless in one place; and probably the use of fences around the court is a fundamental difference between the sports compared, meaning that there are fewer in-game interruptions in rink hockey.

Another important point in external load quantification is to analyze the mechanical load of a rink hockey match. Compared to other indoor and outdoor team sports, the main difference lies in the way that the players move about the court. Some research has been done in basketball in this field, and in two works[21,22] the authors found mean values of PL/min smaller than the values found in our research and in soccer we found one piece of research[31] analyzing four official matches of under-18 players with mean values smaller than those of our data as well. It may be that the use of skates to move in comparison with running had less impact on the vertical axis, thus accumulating less PL/min. As we mentioned in the introduction, the major gap in the literature with regard to rink hockey means that there is no evidence that the biomechanics of skating differ from running in terms of external load, although the results seem to suggest that the team analyzed had more DT than other indoor sports in relative mean values but with lower PL values in relative mean values as well. Some research[32] suggests that the ratio between velocity load (DT/min) and mechanical load (PL/min) could be a metric of the amount of force or ground impulses required per unit of displacement, used to asses neuromuscular or running (in our case skating) efficiency; with our results, this ratio may be higher than other running sports (more distance per force load), with the aforementioned relationship of more DT/min and lower PL/min values.

It is interesting to note that there is a trend in the difference between the number of ACC and DEC in all players in absolute and relative results. In rink hockey, the use of skates may mean that stopping a movement is more demanding than starting one. When players complete an action, their movement will normally continue due to the wheels, hence a DEC action probably requires a major amount of eccentric strength and energy expenditure. These results tally with other basketball research[22] conducted also with WIMU sensors in which, in 3 different court conditions, all the player positions studied had more ACC than DEC per minute in three different 5 vs 5 game formats. On the other hand, three soccer research works[33–35] show that the mean values per minute of ACC are similar to the mean values per minute of DEC. In any event, the deceleration action is important because it is part of a change-of-direction skill, which is key to superior performance[36].

In relation to the second aim of the study, the findings tallied with previous rink hockey-related research. We found no differences between positions in any of the variables analyzed, as neither have the authors of previous research works[3]. These results may be accounted for by the high exchange of positions between players during the match, in which the great dynamics of the sport leads all players to occupy different positions. On the other hand, on comparing our findings to those of other studies that analyze players' external load by positions in other sports with local or global positioning systems, we observed differences in distances covered at different speeds, accelerations and decelerations by positions. As in the case of basketball[37], where power forwards presented the lowest total external load (similar variable to PL) compared to other positions; or in another basketball study, which suggested that basketball centers had lower acceleration and deceleration demands during a match, whereas there were no differences between guards and forwards; or finally in handball[38], where backs were more prone to engaging in high-intensity events (accelerations, changes of direction and decelerations) than the other positions. It is interesting to note that despite the small sample size, this finding could make rink hockey special, as in the literature reviewed, and to the best of our knowledge, it could be the only indoor team sport where there are no differences between positions in terms of external loading.

The previous statement, and others in the discussion, should be approached with caution, because only one team, playing at home, was analyzed, meaning that other spurious variables not analyzed, such as playing away, winning or losing, were not taken into account and could interfere in the results.

## CONCLUSIONS

In conclusion, this work describes, for the first time, competitive rink hockey physical demands, in terms of external load, in an elite team context. In this regard, it is important to stress that there are no differences in the external load variables measured between EX and IN positions in rink hockey matches. We would encourage other sport scientists to analyze and report the external load data from other rink hockey teams in order to further knowledge of this sport.

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# 8. Estudi 2

Aquest estudi es correspon amb el següent article:

Integrating External and Internal Load for Monitoring Fitness and Fatigue Status in Standard Microcycles in Elite Rink Hockey

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**ABSTRACT**

The aims of this study were threefold: firstly, to present an integrative approach to external and internal load dynamics for monitoring fitness and fatigue status of specific in-court rink hockey training sessions in a standard microcycle; secondly, to assess the differences between training sessions and matches; the third and final aim was to assess the association between external and internal load metrics. The external load, using a local positioning system, and internal load, using the declared rate of perceived exertion, were measured during 23 in-season microcycles for 9 top-level players. Training load data were analysed with regard to the number of days before or after a match (match day [MD] minus or plus). In relation to the first aim, internal and external load metrics merged into a single integrated system using pooled data z-scores provided an invisible monitoring tool that places the players in the fitness-fatigue continuum throughout the different microcycle sessions. In this regard, MD-4 and MD-1 sessions tend to place, with a low dispersion, the players in a “low external and internal load” zone. On the contrary, in MD-3 and MD-2 sessions, as well as in MD, in which higher loads were recorded, most of the players were within a “high external and internal load” zone with a tendency towards dispersion towards the fitness or fatigue zones. Finally, and with regard to the second and third aims, an inverted “U-shape” load dynamic related to the specific goals of each training session was the main finding in terms of comparison between MD; a load peak between MD-3 and MD-2 sessions and a significant decrease in all the load variables in MD-1 sessions were found; and high-to-low correlations were found between external and internal load metrics. This study presents an integrative approach to the external and internal load of players for monitoring fitness and fatigue status during a standard microcycle in rink hockey that might provide team sport staff members with a deeper understanding of load distribution in the microcycle in relation to the match.

***Keywords:*** team sport, load control, ultrawide-band, LPS, GPS

## INTRODUCTION

Workload in the context of sports training has been defined as the input variable which, assuming a certain level of stress, is manipulated to obtain a desired response (Impellizzeri et al., 2019). While training load is totally manipulable, competition load, due to its intrinsic characteristics such as results, place in the league table, stage of the season or type of league, is much less so and is limited to the possibility of regulating player exposure to it (minutes of play). Load can be described as internal or external (Impellizzeri et al., 2019). External load (EL) is the work completed by the player independently of his or her internal characteristics; for example, it is described in terms of distance, accelerations, decelerations, or sprints, among others (Varley & Aughey, 2013). The resulting physiological, psychological, and biomechanical stress imposed, described as internal load (IL), drives player adaptation response (Vanrenterghem et al., 2017). The outcome of any training intervention is therefore the consequence of both EL and IL, hence reliable monitoring tools are crucial to the optimisation of athletic performance (Impellizzeri et al., 2019) and to a better understanding of the factors affecting sport performance and recovery, since the uncoupling or divergence of EL and IL may differentiate between a non – fatigued and a fatigued athlete (Thorpe et al., 2017). Current models of the fitness – fatigue relationship use the association between EL and IL (Delaney et al., 2018), considering "fatigue" as the ability to complete a task or training session with an altered IL response which recent had been achievable with a lower IL response and "fitness state" as the opposite, the ability to accumulate a given EL with a lower IL response.

Thanks to tracking technology, athletes, coaches and sport scientists, can easily compile EL parameters to help practitioners and coaches to plan, evaluate, structure and optimise their training methodology (Borresen & Lambert, 2009). The use of electronic performance and tracking systems has helped to compare competition demands to training session drills and consequently modulate the intensity and volume of these training sessions according to the match day (Buchheit et al., 2014). Moreover, the use of subjective scales to record the declared exertion also makes it possible to obtain information about IL (Foster et al., 2001).

The organization of training loads can be divided into macrocycles, mesocycles and microcycles (Naclerio et al., 2013). These divisions make it possible to organize the load from very large time cycles (for example macrocycles that encompass two seasons), through mesocycles that group several weeks or months of training, up to weekly microcycles. The most recent research in team sports is beginning to identify the microcycle as the most important planning unit in this type of sport in this specific case, understanding the microcycle not as the training week, but as the time that passes between one game and another (Tarragó et al., 2019). Indeed, many studies have provided comprehensive information about EL of outdoor elite team sports during matches, and some studies have furnished the same information about indoor elite team sports (Gómez-Carmona et al., 2020; Ribeiro et al., 2020; Vázquez-Guerrero et al., 2019), including high-intensity actions and metabolic variables. Research relating elite teams' in-season microcycles in outdoor sports is on the increase (Akenhead et al., 2016; Martín-García et al., 2018; Oliveira et al., 2019) but is virtually non-existent in indoor sports (Illa et al., 2020).

Being an indoor sport, rink hockey is a team sport involving skates and a stick and is characterised by high-intensity actions such as accelerations, decelerations, sprints, and changes of direction (Fernández, Varo, et al., 2020). Rink hockey is played in a 40 x 20 meters court like futsal or handball, but with fences, a structural difference that means that there are fewer interruptions than in these other sports. It is played by two teams of four players and a goalkeeper, and official matches have two halves of 25 minutes; the number of players and the court size make rink hockey more similar to futsal than to basketball and handball in terms of density of players. Finally, the use of roller skates makes the movement of the players on the court much easier; they are able to cover large distances, sometimes without effort. Finally, decelerations and accelerations are the key actions in this sport (Fernández, Varo, et al., 2020). While the use of technology in certain team sports modalities has increased in the last decade, research into conditional demands is scant. Some research has addressed official matches (Fernández, Varo, et al., 2020; Merino Tantiña et al., 2014) and the most demanding passages in certain drills (Fernández, Novelles, et al., 2020), although microcycle training load dynamics has never been described.

Accordingly, this research pursued three aims: (i) to present an integrative approach to EL and IL dynamics for monitoring the fitness and fatigue status in the specific in-court training sessions of an elite rink hockey team for a standard one-match-per-week microcycle; (ii) to evaluate the differences in EL and IL metrics between training sessions and match; and (iii) to assess the association between EL and IL metrics.

## MATERIALS AND METHODS

### *Participants*

Elite professional rink hockey players (n = 9, age: 29.8 ± 5.77 years, weight: 79.5 ± 5.50 kg, height 180.4 ± 4.03 cm, all measurements mean ± standard deviation) participated voluntarily in the study, whereas the goalkeepers were not included. In the two seasons analysed, the team won the Spanish First Division championship and 7 of the 9 players of the sample played for their respective national teams in official tournaments. The data analysed came from daily player monitoring, in which player activities were routinely measured throughout the season. The experimental procedures used in this study were approved by the local Ethics and Scientific Committee and all the players signed an informed consent form before participating.

### *Methodology*

A retrospective observational study was carried out during the 2018-2019 and 2019-2020 competitive seasons (in the latter only until March 2020 due to COVID-19). A non-experimental descriptive method was used to identify the demands of rink hockey microcycle training sessions and matches and to evaluate the differences between days. A correlation analysis was conducted to describe the relationship between EL and IL metrics. The training load data were analysed with regard to the number of days before the match [match day (MD) minus X days] (Akenhead et al., 2016).

As it has been noted in the introduction, the microcycle it is the most important programming unit in team sports training. Tarragó et al. (2019) defined a microcycle as the time that elapses between competitive matches, and stated that its goal is to achieve the best training possible and consider the loads of the competitive matches within the dynamic of the weekly load, considering them the most important factor that affects the other sessions. The number of competition matches per week, days between matches and the physical condition of the players and the team, among other conditioning factors, affected the structure of each microcycle throughout the season. Due to all these variations, the inclusion criteria for the standard microcycles analysed were: 1) microcycles with only one match per week, 2) microcycles with four training sessions before the match, 3) microcycles with one day of rest after the previous match and 4) microcycles in which the matches were official. Once the microcycles had been chosen, the inclusion criteria for the players analysed in each session were: 1) the player had to complete the entire session and 2) the player had to be available for the match. With these criteria, a total of 23 in-season microcycles were chosen out of a total of 75, with 20 MD-4 sessions, 23 MD-3 sessions, 20 MD-2 sessions, 11 MD-1 sessions and 8 MD official matches. The mean durations (and standard deviations) of the sessions were, 62.3 ± 4.26 minutes for the MD-4, 85.4 ± 4.91 minutes for MD-3, 76.5 ± 8.46 minutes for MD-2, 56.1 ± 3.24 minutes for MD-1 and 90.4 ± 4.99 minutes for MD. The missing session data (for example, only 11 MD-1 sessions of the 23 microcycles were analysed) were due to factors beyond the researcher's control (e.g., technical issues with equipment) or because training sessions had been arranged on other training courts and facilities for logistical and schedule reasons. The matches and specific in-court training sessions analysed were always played on the same court (always at home), ensuring the same environmental conditions.

The training sessions of the microcyles analysed in this research were always comprised of an integrated content (i.e. tactical, technical and physical factors were amalgamated) and in line with the structured training and structured microcycle methodology (Tarragó et al., 2019). The main goals and drills used in each training session are provided in figure 1.

***Procedures***

Data logging to evaluate EL was performed with a local positioning system (WIMU PRO™, Realtrack Systems SL) and its corresponding software (SPRO™, Realtrack Systems SL, version 962). The devices were fitted to the upper back using tight harnesses. The WIMU PRO™ features four 3D accelerometers (full-scale out output ranges are ± 16 g, ± 16 g, ± 32 g, ± 400 g, 100 Hz sample frequency), three gyroscopes (8000º/s full-scale out output range, 100 Hz sample frequency), a 3D magnetometer (100 Hz sample frequency), a GPS (10 Hz sample frequency) and ultra-wideband (18 Hz sample frequency). The ultra-wideband system was installed on the court as follows: 6 antennae with ultra-wideband technology were placed 5 m away from the perimeter line of the field. The WIMU PRO system presented a high intra-class correlation coefficient value for the x-coordinate (0.65), a very high value for the y-coordinate (0.85) and a good % technical error of measurement: 2 (Bastida Castillo et al., 2019).

The following variables were calculated in absolute terms to describe EL: distance travelled in meters (DT; m); high-speed skating, distance covered above 18 km/h in meters (HSS $>18 km \cdot h^{-1}$; m); player load, vector magnitude, expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each one of the 3 planes divided by 100 in arbitrary units (PL; AU); number of high-intensity accelerations (ACC; $>2 m \cdot s^{-2}$; n) and number of high-intensity decelerations (DEC; >2m·s$^{-2}$; n). All of these variables were selected because they were the most commonly used ones in other competition load descriptive studies and the thresholds used were the ones emphasised most in indoor sport research and previously described in rink hockey (Fernández, Varo, et al., 2020).

Each player's declared exertion (declared RPE) was collected approximately 30 min after each specific in-court training session or match using the 0-10 point Borg's rate of perceived exertion scale modified by Foster et al. (2001), with its respective verbal anchors, in order to collect subjective IL estimations. All the players were familiar with the use of the scale. A smartphone app was used to avoid bias and maintain subjectivity in player response. Subsequently, specific in-court session declared RPE (s-RPE) was calculated by multiplying the specific session (or game) duration in minutes by the individual declared RPE scores for the training (or game) and was presented in arbitrary units (a.u.) (Foster et al., 2001). s-RPE has been proposed as a cost-effective alternative to heart rate-based methods as a global measure of training intensity that may more accurately quantify IL in intermittent sports (Impellizzeri et al., 2004; Paulson et al., 2015). Both declared RPE (0-10 point scale) and s-RPE (a.u.) results were used for further analyses.

***Statistical analysis***

All statistical analyses were conducted with RStudio version 1.3.1093 (RStudio, Inc.) and "readxls", "tidyr", "dplyr", "ggridges", "plyr", "ggplot2", "scales", "viridis", "pipeR", "effsize", "bootES", "officer", and "rvg" packages. Descriptive results were reported as mean ± standard deviation and a z-score analysis was conducted with the pooled s-RPE data and the mean of all z-score EL variable pooled data. The data failed all the tests for homogeneity of variance (Levene's test) and most of the variables and MD for normality (Shapiro–Wilk test). A bootstrap confidence interval (CI) approach was used to perform the hypothesis test to assess the differences between MDs because the assumptions of this method were aligned with our data (Tian, 2010). A residual resampling model with 10,000 bootstrap samples and 95% bias-corrected and accelerated method (BCa 95% CI) was used to calculate the CI of F-values of repeated-measures ANOVA for each variable and established that the null hypothesis, that there were no differences, was true if 1 fell within the CI limits (Plonsky, 2015). The same bootstrap CI approach with a simple resampling model was used to evaluate the post hoc pairwise comparisons. The mean difference and effect size value was computed and presented as pairwise change. Thresholds for effect size (ES) statistics were (ES<0.20), trivial;

(0.20<ES<0.59), small; (0.60<ES<1.19), moderate; (1.20<ES<1.99), large; and (ES>2.0), very large (Hopkins et al., 2009). Finally, a bootstrapped Pearson correlation test was conducted to quantify the correlation between s-RPE and all the EL variables. The magnitude of correlation coefficients, according to Hopkins (2016), was considered trivial (r<.1), small (.1<r<.3), moderate (.3<r<.5), large (.5<r<.7), very large (.7<r<.9), almost perfect (r>.9) or perfect (r=1). All the reported P-values were the likelihoods of the absolute effect sizes being observed if the null hypothesis of zero difference was true (Plonsky, 2015).

## RESULTS

The EL and IL descriptive results are represented in Figure 5 and in Table 5. The MD-3 training sessions were the ones with the highest values (except the HSS variable, where the MD is the session with the highest values). In addition, Figure 5 presents an overview of all the microcycle mean values, with descriptive results relative to match values and z-score values of EL (presented as the mean of all z-score EL variables) and s-RPE metric for each training session; MD-1 sessions were the ones with the lowest relative load values and the lowest EL and IL demands measured in z-score values.

*Table 5. Descriptive statistics (mean ± standard deviation) for all variables each match day.*

| Variables | MD-4 | MD-3 | MD-2 | MD-1 | MD |
|---|---|---|---|---|---|
| DT (m) | 5,289 ± 466 | 7,035 ± 754 | 6,463 ± 1014 | 4,324 ± 379 | 5,568 ± 750 |
| HSS (m) | 560 ± 212 | 727 ± 225 | 683 ± 245 | 256 ± 103 | 739 ± 209 |
| PL (a.u.) | 26.9 ± 2.70 | 34.8 ± 4.15 | 31.6 ± 4.85 | 21.8 ± 2.10 | 34.0 ± 4.54 |
| ACC (n) | 122 ± 22.0 | 172 ± 33.7 | 149 ± 31.9 | 82.4 ± 17.6 | 160 ± 26.6 |
| DEC (n) | 99.9 ± 21.7 | 143 ± 31.9 | 121 ± 30.1 | 64.4 ± 18.3 | 143 ± 25.8 |
| Declared RPE (0-10 scale) | 5.71 ± 1.64 | 6.16 ± 1.78 | 5.80 ± 1.87 | 2.43 ± 0.90 | 5.29 ± 1.45 |
| s-RPE (a.u.) | 356 ± 107 | 501 ± 153 | 454 ± 158 | 126 ± 47.3 | 474 ± 129 |

*Note. DT = Distance travelled, HSS = High-speed skating, PL = Player Load, ACC = High-intensity accelerations, DEC = High-intensity decelerations, RPE = Rate of perceived exertion, s-RPE = Rate of perceived exertion × total duration of session, MD = Match day.*

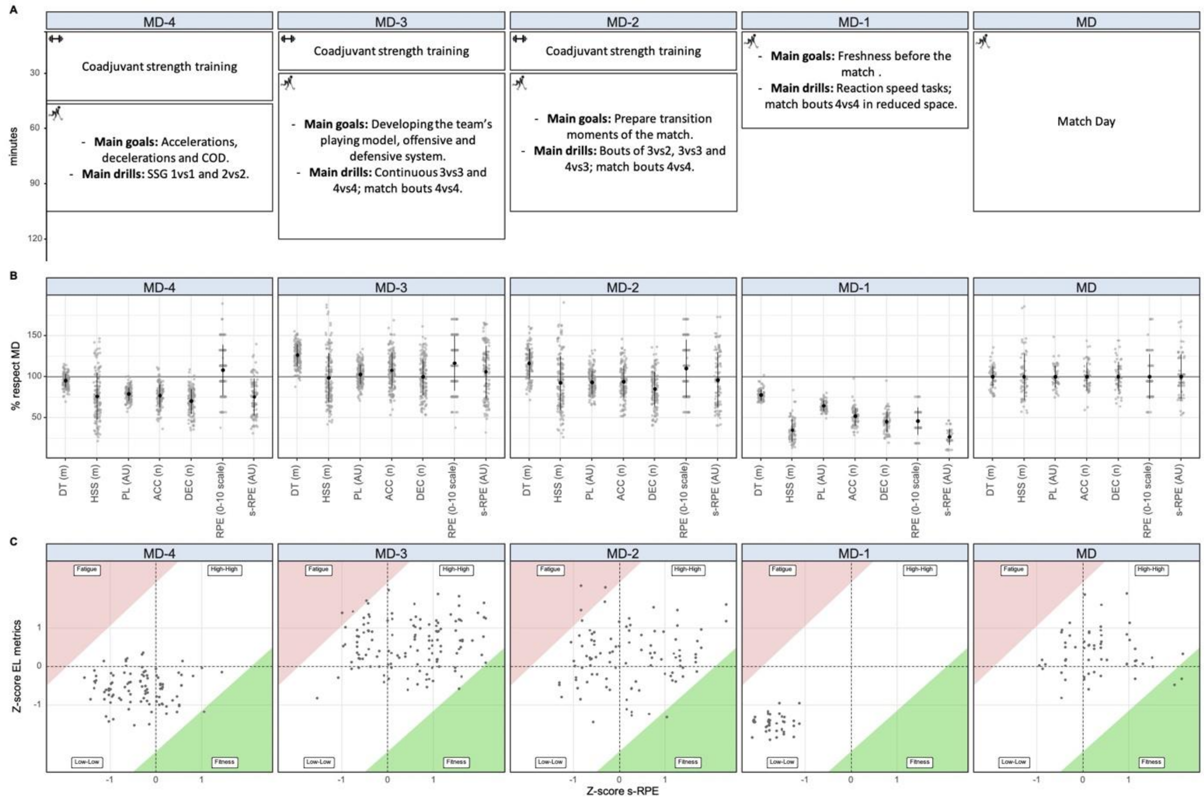


*Figure 5. Integrative approach overview of a standard microcycle. (A) Main goals, characteristics and training drills used in each session. (B) Mean, standard deviation and data distribution of each session expressed as a percentage of match values. (C) Distribution of the mean of the EL metrics z-scores (EL metrics z-scores) and the IL s-RPE z-scores of pooled data from all sessions. Note. DT = Distance travelled, HSS = High-speed skating, PL = Player Load, ACC = High-intensity accelerations, DEC = High-intensity decelerations, RPE = Declared rate of perceived exertion, s-RPE = Rate of perceived exertion × total duration of session, MD = Match Day.*

The ANOVA results of all the variables studied are presented in Table 6, there being significant differences in all the metrics analysed. Finally, the change of each variable in each pairwise comparison between the different MD is represented in Table 7 in the form of absolute changes (in the respective units) and effect size changes (in Cohen D units). MD-3 were the training sessions most similar to the match, except in DT, ACC and declared RPE, in which it surpassed the match values; on the other hand, MD-1 were the training sessions with the most significantly lowest values in all the metrics studied compared to the other training sessions and the match.

*Table 6. Bootstrap ANOVA results for each variable*

| ***Variable*** | ***F*** | ***Bootstrap**** | | | |
|---|---|---|---|---|---|
| | | ***Bias*** | ***Std. Error*** | ***BCa 95%CI Lower*** | ***BCa 95%CI Upper*** |
| DT (m) | 242 | 24.1 | 25.7 | 185 | 266.3 |
| HSS (m) | 92.4 | 9.52 | 12.0 | 65.1 | 106.0 |
| PL (a.u.) | 229 | 22.9 | 23.7 | 172 | 251 |
| ACC (n) | 224 | 22.0 | 23.0 | 167 | 245 |
| DEC (n) | 261 | 25.3 | 26.6 | 199 | 286 |
| Declared RPE (0-10 scale) | 70.5 | 10.2 | 10.9 | 45.4 | 81.1 |
| s-RPE (a.u.) | 111 | 15.8 | 15.1 | 80.5 | 124 |

*Note. DT = Distance travelled, HSS = High-speed skating, PL = Player Load, ACC = High-intensity accelerations, DEC = High intensity-decelerations, RPE = Rate of perceived exertion, s-RPE = Rate of perceived exertion × total duration of session. The null hypothesis was rejected if 1 did not fall within BCa 95% CI limits. *Bootstrap results are based on 10,000 bootstrap samples.*

*Table 7. 95% Confidence interval of absolute change and effect size change between match days. The confidence intervals are based on the BCa method and 10,000 bootstrap samples. Significant differences ($p<0.05$) are displayed in bold.*

| **Pairwise** | | **DT (m)** | | **HSS (m)** | | **PL (a.u.)** | | **ACC (n)** | | **DEC (n)** | | **Declared RPE (0-10 scale)** | | **s-RPE (a.u.)** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *95CI lwr.* | *95CI upr.* | *95CI lwr.* | *95CI upr.* | *95CI lwr.* | *95CI upr.* | *95CI lwr.* | *95CI upr.* | *95CI lwr.* | *95CI upr.* | *95CI lwr.* | *95CI upr.* | *95CI lwr.* | *95CI upr.* |
| MD - MD-4 | Abs. Δ | **74.6** | **488** | **118** | **246** | **5.93** | **8.47** | **29.9** | **45.5** | **35.9** | **50.9** | -0.91 | 0.09 | **78.9** | **158** |
| | ES Δ | **0.12** | **0.85** | **0.54** | **1.14** | **1.73** | **2.49** | **1.23** | **1.93** | **1.53** | **2.21** | -0.58 | 0.05 | **0.68** | **1.35** |
| MD - MD-3 | Abs. Δ | **-1,687** | **-1,241** | -48.4 | 77.5 | -2.11 | 0.60 | **-20.5** | **-3.38** | -8.01 | 8.73 | **-1.33** | **-0.36** | -68.0 | 17.1 |
| | ES Δ | **-2.28** | **-1.57** | -0.23 | 0.35 | -0.50 | 0.13 | **-0.65** | **-0.10** | -0.27 | 0.27 | **-0.82** | **-0.21** | -0.48 | 0.11 |
| MD - MD-2 | Abs. Δ | **-1,141** | **-634** | -6.35 | 127 | **0.97** | **3.80** | **1.91** | **19.1** | **13.4** | **30.2** | -1.04 | 0.03 | -25.5 | 65.6 |
| | ES Δ | **-1.23** | **-0.66** | -0.04 | 0.52 | **0.19** | **0.79** | **0.06** | **0.62** | **0.45** | **1.03** | -0.60 | 0.01 | -0.18 | 0.44 |
| MD - MD-1 | Abs. Δ | **1,035** | **1,457** | **429** | **546** | **10.9** | **13.5** | **69.7** | **85.5** | **70.9** | **86.6** | **2.42** | **3.35** | **313** | **386** |
| | ES Δ | **1.68** | **2.66** | **2.52** | **3.53** | **2.89** | **4.14** | **2.79** | **4.11** | **2.89** | **4.10** | **1.86** | **2.68** | **2.81** | **3.86** |
| MD-4 - MD-3 | Abs. Δ | **-1,878** | **-1,606** | **-217** | **-117** | **-8.71** | **-7.14** | **-56.2** | **-43.5** | **-49.4** | **-37.1** | -0.89 | 0.01 | **-179** | **-111** |
| | ES Δ | **-3.05** | **-2.41** | **-0.98** | **-0.53** | **-2.48** | **-1.92** | **-1.96** | **-1.46** | **-1.79** | **-1.31** | -0.52 | 0.00 | **-1.36** | **-0.81** |
| MD-4 - MD-2 | Abs. Δ | **-1,356** | **-989** | **-175** | **-68.0** | **-5.72** | **-3.92** | **-33.5** | **-20.6** | **-27.7** | **-15.4** | -0.58 | 0.39 | **-136** | **-61.8** |
| | ES Δ | **-1.75** | **-1.21** | **-0.76** | **-0.30** | **-1.45** | **-0.98** | **-1.22** | **-0.74** | **-1.06** | **-0.57** | -0.33 | 0.24 | **-1.01** | **-0.46** |
| MD-4 - MD-1 | Abs. Δ | **838** | **1,071** | **262** | **346** | **4.31** | **5.68** | **34.5** | **45.3** | **29.9** | **40.9** | **2.86** | **3.71** | **205** | **256** |
| | ES Δ | **1.79** | **2.57** | **1.41** | **1.92** | **1.64** | **2.29** | **1.54** | **2.29** | **1.36** | **2.06** | **1.86** | **2.60** | **2.10** | **2.81** |
| MD-3 - MD-2 | Abs. Δ | **362** | **769** | -9.03 | 97.7 | **2.12** | **4.12** | **15.3** | **29.8** | **14.6** | **28.3** | -0.13 | 0.83 | **4.78** | **85.9** |
| | ES Δ | **0.41** | **0.88** | -0.04 | 0.42 | **0.45** | **0.94** | **0.45** | **0.91** | **0.46** | **0.92** | -0.07 | 0.46 | **0.03** | **0.57** |
| MD-3 - MD-1 | Abs. Δ | **2,556** | **2,843** | **430** | **512** | **12.1** | **13.7** | **82.9** | **96.0** | **72.1** | **84.9** | **3.30** | **4.14** | **343** | **404** |
| | ES Δ | **3.61** | **4.54** | **2.13** | **2.66** | **3.14** | **3.91** | **2.64** | **3.37** | **2.42** | **3.10** | **1.97** | **2.63** | **2.45** | **3.10** |
| MD-2 - MD-1 | Abs. Δ | **1,954** | **2,328** | **380** | **474** | **8.89** | **10.7** | **60.4** | **73.6** | **50.6** | **63.5** | **2.91** | **3.84** | **294** | **363** |
| | ES Δ | **2.17** | **2.85** | **1.78** | **2.32** | **2.08** | **2.66** | **2.05** | **2.74** | **1.81** | **2.45** | **1.73** | **2.34** | **2.13** | **2.72** |

*Note. DT = Distance travelled, HSS = High-speed skating, PL = Player Load, ACC = High-intensity accelerations, DEC = High-intensity decelerations, RPE = Rate of perceived* *exertion, s-RPE = Rate of perceived exertion × total duration of session, MD = Match Day, CI = Confidence interval, ES = Effect Size, lwr = lower, upr = upper.*

The correlation data analysed between EL and IL (s-RPE) are shown in Figure 6. There was a large positive correlation with DT and PL variables, moderate with ACC and DEC variables and a small positive correlation with the HSS metric.

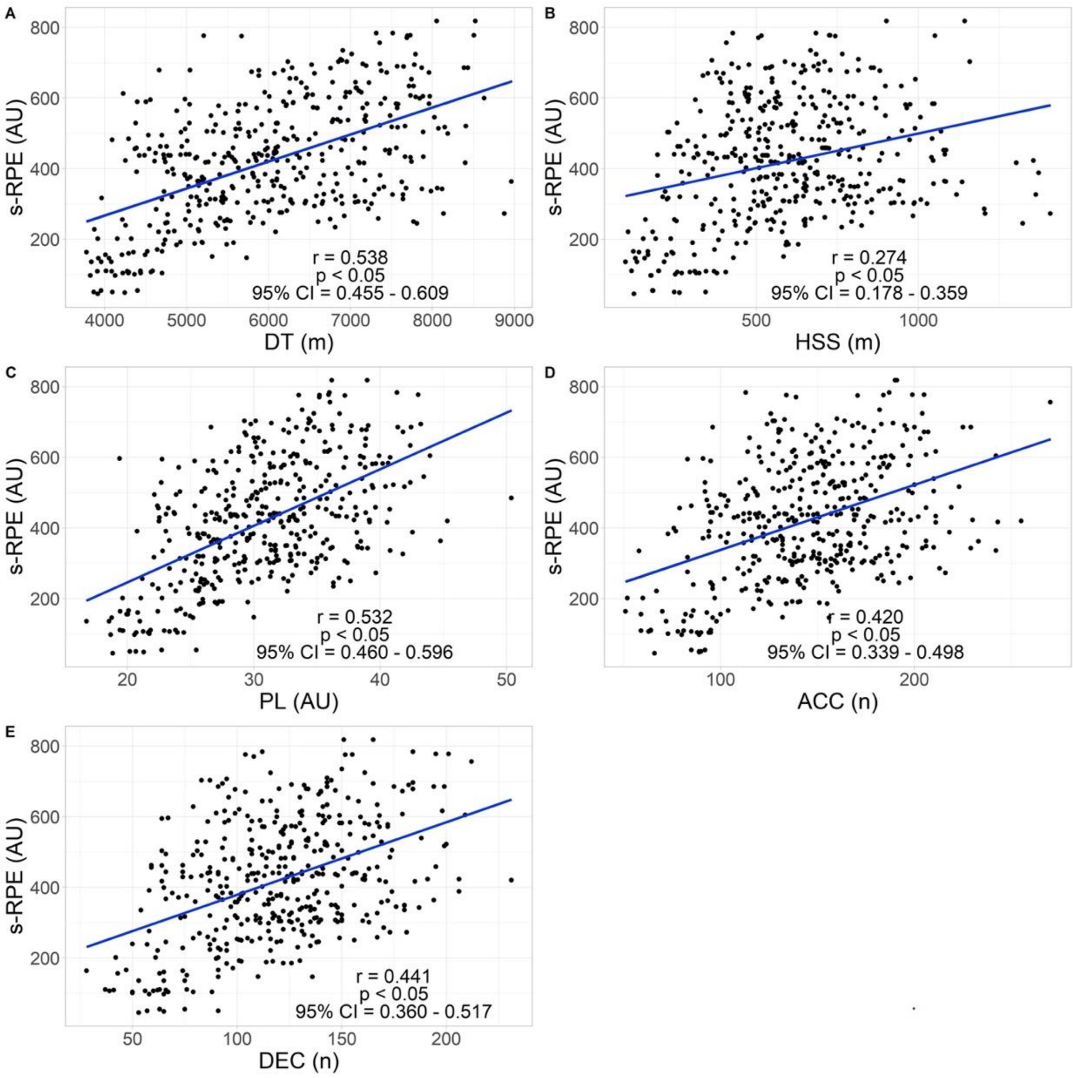


*Figure 6. Correlation between EL metrics and session RPE (s-RPE). (A) s-RPE and distance travelled. (B) s-RPE and high-speed skating distance. (C) s-RPE and Player Load. (D) s-RPE and number of high-intensity accelerations. (E) s-RPE and number of high-intensity decelerations. Note. DT = Distance travelled, HSS = High-speed skating, PL = Player Load, ACC = High-intensity accelerations, DEC = High-intensity decelerations, s-RPE = Rate of perceived exertion × total duration of session.*

## DISCUSSION

The aims of this research were (i) to present an integrative approach to the EL and IL dynamics for monitoring the fitness and fatigue status of specific in-court training sessions of an elite rink hockey team for a standard microcycle, (ii) to evaluate the EL and IL differences between all the training sessions and matches and (iii) to assess the correlation between EL and IL metrics. To the best of our knowledge, this is the first study to carefully describe the EL and IL dynamics of a microcycle of an elite rink hockey team. In this regard, our results revealed an inverted "U-shape" load dynamics in which MD-3 and MD-2 were the two training sessions with the greatest EL and IL of the microcycle in comparison with the other sessions and slightly above the match. Finally, and with regard to the association between EL and IL metrics, large and moderate correlations were found between volume-related variables and s-RPE and low correlations were found between high-intensity-related variables and s-RPE.

### *Integrative approach to training loads*

One of the novelties presented by this study was the determination of the EL and IL dynamics during a standard microcycle comprised of two consecutive seasons. Figure 5 provides a visual overview of a standard microcycle content (Figure 5, A), training load dynamics (Figure 5, B) and an integrative approach of EL and IL for player fitness and fatigue status monitoring based on the proposals by Gabbett et al. (2017) and Delaney et al. (2018) (Figure 5, C).

With regard to load dynamics, our monitoring approach showed that both EL and IL represented an inverted "U-shape" curve throughout a standard microcycle (Figure 5, B). Regarding EL, the inverted "U-shape" presented is like other EL dynamics described elsewhere in other team sport microcycles, such as soccer (Akenhead et al., 2016; Los Arcos et al., 2017; Martín-García et al., 2018; Owen et al., 2017). Other research in soccer showed a decrease from MD-4 sessions to MD (Stevens et al., 2017), and finally, Malone et al. (2014), also in soccer, found no differences between MD-4, MD-3, and MD-2 training sessions. This inverted "U-shape" curve seems to correspond to a tapering strategy (Martín-García et al., 2018) in which EL decreases as match day approaches. Interestingly, the most notable characteristic of IL dynamics in our study was the difference between the inverted "U-shape" of the s-RPE metric (following the same pattern as EL metrics) versus the flat shape described by the declared RPE (0-10 point scale) variable throughout MD-4, MD-3, and MD-2 training sessions (Figure 5, B). This declared RPE (0-10 point scale) dynamic might be explained by the fact that this variable is a nominal score given by the player that mainly describes mean training intensity (Haddad et al., 2017), while the s-RPE metric takes not only the intensity but also the duration of the session into consideration (Foster et al., 2001). Excepting MD-1, MD-4 is the shortest of the other three types of training days; this is why, when multiplying the declared RPE by time, the s-RPE was lowest in MD-4 training sessions.

Finally, Figure 5 (C) presents the IL and EL metrics merged into an integrated system using pooled data z-scores; this type of load monitoring approach, based on Gabbett et al., (2017) and Delaney et al. (2018), provides a monitoring tool that places the players in the fitness-fatigue continuum throughout the different microcycle sessions without using tests. This approach uses the relationship between IL and EL metrics in attempt to detect uncoupling between metrics, in other words, attempt to detect when a given EL had a lower (fitness) or greater (fatigue) IL response. Moreover, the use of pooled data helps the observer to see the type of training session and its dispersion with respect to the others, and the quadrant in which it is located intra and inter sessions. In this regard, Figure 5 (C) shows that MD-4 and MD-1 sessions tend to place, with low dispersion, the players in a “low EL and IL” zone, guaranteeing a recovery process, especially if combined with an optimal well-being status (Gabbett et al., 2017). On the contrary, in MD-3 and MD-2 sessions, as well as in MD, in which higher loads were recorded, most of the players were placed in a “high EL and IL” zone with a tendency towards dispersion towards the fitness or fatigue zones. This indicates that when players are exposed to high loads, and although most of them will exhibit an expected outcome response (“high El and IL”), the chances of having an unexpected response that would represent an improved fitness status or a fatigue process might be increased. Although this is beyond the scope of this study, such individual unexpected responses (fitness and fatigue) merit further attention in order to individualize the training process better by adjusting training loads and modifying training content.

***Differences between sessions in the microcycle***

The second aim of this study allowed us to compare training sessions and match EL and IL. One of the main findings was that in the MD-4 training sessions, all EL variables and s-RPE were below the match and MD-3 and MD-2 training sessions, but declared RPE was not different from the match and MD-3 and MD-2 training sessions. The differences in IL metrics (s-RPE vs. declared RPE), as previously stated, can be explained by the difference in definition of the metrics: a nominal intensity score reported by declared RPE versus the inclusion of the duration of the session in s-RPE. Moreover, this specific difference in MD-4 sessions and the rest of the sessions might also be accounted for by the fact that the players were exposed to the longest weekly (45 minutes) coadjuvant strength training (Gómez et al., 2019) at the gym followed by in-court sessions focusing on SSG (Figure 5, A). Therefore, coadjuvant strength training in the gym just before the beginning of the specific training session could have had an impact on the declared RPE measured. This content training arrangement has been defined as concurrent training (Fyfe et al., 2014), which might have an effect on EL variables of the specific in-court part of the session (lowering the load) and an effect on the declared RPE (increasing the load), but not on the s-RPE because of the shortert in-court training time. In line with our results, Enright (2014) showed that in soccer, when resistance training was performed before specific soccer training, the specific training declared RPE was significantly higher than the inverse training sequence. Although several mechanisms may account for the difference between IL variables, none of them alone can definitely justify the results. However, knowing the reality of IL and EL dynamics can help staff members to take decisions to optimise MD-4 sessions loads, for example in this specific scenario, separating the strength session from the in-court session (into morning - afternoon sessions) would allow for a greater recovery between sessions that would mean that the perception of effort of the first session did not excessively affect the second one.

Another relevant finding regarding MD comparison was that MD-3 and MD-2 training sessions presented the greatest load demands compared to MD. MD-3 training sessions were superior in DT, ACC and declared RPE, although no significant differences were found between HSS, PL, DEC and s-RPE compared to MD; MD-2 sessions were significantly superior in DT; equal in HSS, declared RPE and s-RPE and significantly lower in PL, ACC and DEC with regard to MD (Table 3). These results were similar to those reported by Illa et al. (2020) in futsal, where EL was equal to or greater than MD in the central part of the microcycle but different to outdoor team sports, such as soccer (Martín-García et al., 2018; Stevens et al., 2017), where it proved impossible to reach MD levels in the training sessions and especially in MD-2 training sessions. Unlike indoor team sports, more time may be required to recover from intense pre-match training sessions in outdoor team sports, and for this reason most of the training load was prescribed between MD-4 and MD-3 sessions. The training contents prescribed in MD-3 and MD-2 training sessions described in Figure 5 (A) could explain the greater load demands in EL and IL (in some metrics); in line with this, some research in basketball (Vazquez Guerrero et al., 2018) suggests that the bigger the space used in specific in-court drills the greater the EL imposed upon the players. The use of roller skates in rink hockey makes it easy to move around the court and more difficult to remain motionless in one place, and this could be a reason for the higher absolute values of distance, and high-speed distance than in other indoor sports (Fernández, Varo, et al., 2020). Another interesting point is that DEC is a variable that is always lower on training days than on the match days (or at most equal). The main point is that, as mentioned in the introduction, DEC in rink hockey may be the variable that makes a difference; for example, when a player returns from an attacking phase to a defensive phase an intense and short deceleration may make the difference between a good defensive transition (timely, fast, and effective) and a bad one (late and tactically un – successful). Finally, as described in Figure 5 (C), all EL and IL metrics (based on the s-RPE metric) presented a major dispersion in MD-3 and MD-2 sessions, albeit with a tendency to be in the "high EL and high IL" quadrant, particularly MD-3 sessions.

Finally, with regard to MD comparison, it is also interesting to emphasise that there was a decrease in all the variables studied as match day approached (MD-1 sessions). The consistent finding of a reduction in MD-1 training sessions of EL and IL denotes a tapering strategy to guarantee freshness before competition. Many studies in team sports have demonstrated that this strategy is effective in ensuring that players will be totally competition-fit (Akenhead et al., 2016; Illa et al., 2020; Los Arcos et al., 2017; Martín-García et al., 2018; Owen et al., 2017). More specifically, if we examine competitive match loads in the weekly load dynamic, considering them as an important factor that conditions the other training sessions (Tarragó et al., 2019); then the MD-1 sessions tapering strategy in team sports consists of lowering EL and IL, ensuring recovery and guaranteeing players' match readiness (Svilar et al., 2019). In summary, and as described in Figure 5 (C), MD-1 presented a "low EL and low IL" profile with a low data dispersion, ensuring a consistent tapering strategy in the team analysed.

***Correlation between EL and IL***

The third and final objective of this research was to examine the correlations between EL and IL. The analysis of the relationship between the EL variables studied and the s-RPE IL metric is presented in the Figure 6. The correlations studied in the team analysed ranged from high to low in all the metrics selected; DT and PL were the two variables with the highest values of correlation with s-RPE with high values; HSS was the lowest correlated variable with s-RPE with low results. The volume metrics (DT and PL) findings are in line with those of Scanlan et al. (2014) in basketball, who found that the relationship between accelerometer training load data (similar to PL metric) and s-RPE was very similar to the correlation of our research. In contrast, field-based team sports presented stronger relationships between volume EL metrics and IL (Burgess et al., 2006; Scott et al., 2013) than indoor team sports. On the other hand, high-intensity metrics such as HSS presented the lowest correlation with IL, suggesting, on the one hand, and in line with Fernández et al. (2020), that high-speed movement may be maintained through the use of inertia from a previous effort and not through the player's continual effort, whereby the HSS metric does not account for the players' entire internal response; and on the other hand, in line with Scott et al. (2013), that as the speed of EL criterion increases (the HSS threshold was $18 km \cdot h^{-1}$), the strength of its relationship with s-RPE becomes weaker. Modern rink hockey is based on a very high pace of skating and of ball possession (Perez, 2017). In addition, professional teams seek faster offensive and defensive transitions, which probably increases the HSS volume per match as in soccer, where high – speed running distances have increased in recent years (Bush et al., 2015). This suggests the need for more research into HSS and its degree of correlation with IL and also, into absolute and relative thresholds in HSS. Finally, the results of the correlation analysed suggest that not only do EL variables affect IL response, but also that individual characteristics, psychological status, health, nutrition and the environment, among other intrinsic and extrinsic factors, could affect this response (Impellizzeri et al., 2019). Therefore, taking the different degree of association between EL and IL metrics (ranging from high-to-moderate for volume EL metrics and s-RPE and moderate-to-low for intensity EL metrics and s-RPE) into account, both variables should be measured, since they offer complementary information about conditional demands and elite rink hockey players' response to these demands, respectively.

## CONCLUSIONS

This research, the first of its kind with an elite rink hockey team, presents an integrative approach to the EL and IL of players for monitoring fitness and fatigue status during a standard microcycle. As a skating sport, DEC in rink hockey could be the variable that make a difference in match situations, possibly being this the reason why DEC was the only (along with HSS) EL variable that did not surpass the match volume during a standard microcycle. An inverted "U-shape" load dynamics with a load peak between MD-3 and MD-2 sessions, a mismatch between declared RPE and s-RPE metric in MD-4 sessions and a high correlation between volume EL variables and IL (s-RPE) were the most important findings in this team's microcycle. This could provide team sport staff members (coaches, strength and conditioning coaches and physicians) with a deeper understanding of load distribution throughout the microcycle. The use of z-scores analyses integrating EL and IL builds up an objective decision-support tool for changing and adapting training loads and content. This study is based on a single elite rink hockey team with international top-level players, and the findings provide a basis for the quantification of a standard microcycle, constituting a point of departure for other research into EL and IL in this sport as well as in other team sports.

**Abbreviations:** EL, external load; IL, internal load; declared RPE, declared rate of perceived exertion; s-RPE, session rate of perceived exertion; MD, match day; MD-x, match day [MD] minus X days; DT, distance travelled; HSS, high-speed skating; ACC, high-intensity accelerations; DEC, high-intensity decelerations; ES, effect size.

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# 9. Estudi 3

Aquest estudi es correspon amb el següent article:

The distribution of different intensity demanding scenarios in elite rink hockey players using an electronic performance tracking system
D. Fernández, J.A. Cadefau, N. Serra, G. Carmona.
PLoS One. 2023 Mar 9;18(3):e0282788.

**ABSTRACT**

Despite the traditional use of average values for determining physical demands, the intermittent and fluctuating nature of team sports may lead to underestimation of the most demanding scenarios. All the most demanding scenario-related investigations to date only report one maximal scenario per game, the greatest. However, the latest research on this subject has shown additional scenarios of equal or similar magnitude that most researchers have not considered. This repetition concept started a new way of describing competition and training loads; then the study aims were: first, to quantify and assess differences between playing positions in terms of the most demanding scenarios in official matches; and second, to quantify and assess the differences between playing positions in the repetition of different intensity scenarios relative to the most demanding individual scenario. We monitored nine professional rink hockey players (7 exterior and 2 interior players) in 18 competitive matches using an electronic performance tracking system. The interior players are closest to the opponent's goal, while the exterior players are farthest from it. Peak physical demands variables included total distance (m), distance covered at >18 km·h-1 (m), the number of accelerations (≥2 m·s-2, count) and decelerations (≤-2 m·s-2, count) in 30 s. An average from the top three individual most demanding scenarios was used to define a reference value to quantify the distribution scenario repetition during matches. The results showed that peak demands in rink hockey are position-dependent, with more distance covered by exterior players and more accelerations performed by interior players. In addition, rink hockey matches include multiple scenario exposures that are close to the peak physical demands of a match. Using the results of this study, coaches can prepare tailored training plans for each position, focusing on distances covered or accelerations for exterior players.

## INTRODUCTION

Rink hockey is a dynamic and complex indoor team sport in which players use roller skates to perform intermittent and multidirectional actions, such as accelerations, decelerations, sprints, and impacts. All these actions are performed in a sport-specific framework of driving, shooting, passing, blocking, and defending. Roller skating makes rink hockey a dynamic and fast sport that has relative average demands far greater than other indoor sports [1,2]. Actually, there has been a trend in growth of the use of inertial devices combined with ultra-wide band (UWB) positioning technology to track distance, accelerations, and decelerations during matches and training sessions. Rink hockey has not escaped this, and information about physical and position-related demands can guide sports scientists in rink hockey in the improvement of training programmes and the use of accurate training loads that minimise the risk of injury [3]. Research comparing different team sports [4] showed that rink hockey along with soccer achieves the greatest values in total distance and distance above 18 km/h; and along with basketball achieves the greatest values in the number of accelerations and decelerations. Finally, other research on external loads in official rink hockey competitions has shown that no differences exist between playing positions (exterior and interior players) in the average physical demands imposed by matches [1,2]. After that, coaches could use that information to plan and prepare the training microcycle, and the individual training sessions for players; as rink hockey is a high intensity sport without any differences between positions in terms of average demands.

However, the approach used to assess average physical demand underestimates peak intensities during indoor or outdoor matches due to the intermittent nature of team sports [5]. Some peak moments may be hidden by the average values of all game signals. For this reason, it is necessary to use other monitoring methods to determine the most demanding scenarios (MDS), a period of peak demands experienced by the players during a match, and to implement proper training intensities during sport-specific drills [6].

There has been a growth in research using rolling or moving averages [7] to examine peak competition demands in team sports based on identifying the MDS, also referred to as the most demanding passages in the literature [8,9]. This new approach provides important results that may complement the previous research that mostly focussed on average physical demands. Monitoring the MDS using moving averages helps scientists and coaches understand the parameters that are more important in the analysis of team sports loads because this measure takes into account the naturally intermittent nature of team sports, where, due to the variability of the matches, it is expected that some moments will be more intense than others [10].

Research into peak demands during different epochs (frequently 30 and 60 s) has been conducted using rolling average methods in soccer [11], rugby [12], basketball [6,13], futsal [14], and rink hockey [8]. To date, all the cited investigations only report one maximal scenario per game, with the latest MDS research [9,15] showing additional scenarios of equal or similar magnitude that most researchers and sport scientists did not consider in a given match. The approach of only describing one MDS and not all the different intensity scenarios could underestimate the overall physical demands that occur in a match (e.g., it could be that a player must cope with more than 4 or 5, 30 or 60 s scenarios, near to the MDS). This concept was first described in the literature as the repetition of high (80%–90% of the MDS), or very high (>90% of the MDS) demanding scenarios [9]. Finally, the repetition of scenarios to study the distribution of physical activities in team sports is rare in sports science, and to the authors' knowledge, studies have only reported the distribution of maximal and submaximal demands relative to the peak intensities in basketball matches [16], futsal matches [9,15], and rugby and Australian rules football matches [17,18]. To date, no study has described the distribution of different scenarios of relative intensity in competitive rink hockey and this study aims to do it. In this study, we have aimed to quantify and assess differences between playing positions in terms of the MDS in official matches. In addition, we have aimed to quantify and assess the differences between playing positions in the repetition of different intensity scenarios relative to the individually most demanding scenario. Based on the previous literature in rink hockey, the hypothesis of this study was that interior players experience the same MDS and repetition of different intensity scenarios as the exterior players.

## MATERIALS AND METHODS

### *Design*

We conducted an observational retrospective study in a cohort with a time of follow-up of 2 years during the 2019–2020 and 2020–2021 competitive seasons. In 2019–2020, we were forced to stop in March 2020 due to COVID-19. External load was measured by a UWB electronic performance tracking system (WIMU PROTM, Realtrack Systems, Almeria, Spain) during 18 official matches of a professional team in the highest Spanish tier (Ok Liga), and that also participated in the WSE Rink Hockey EuroLeague.

***Subjects***

Nine professional elite outfield players (age 29.0 ± 5.22 years, weight 78.8 ± 6.20 kg, height 180.6 ± 3.91 cm; all measurements in mean ± standard deviation) participated voluntarily. Goalkeepers did not participate in the study due the goalkeeper's own characteristics and the great technical difference compared to court players. Data from each player and match had to meet two inclusion criteria: (1) players finished the match without injury; and (2) players participated in the entire pre-match training session to ensure that we only included players who had prepared for the match the day previously. The nine players were comprised of seven exteriors and two interiors, as determined by three qualified rink hockey coaches (all of whom had national level certificate in rink hockey coaching from the Spanish Skating Federation, as well as at least three years' experience coaching teams in national leagues). In the possession phase, exterior players are those who play far from the opponent's goal with a lot of mobility, while interior players are those who play closest to the goal with less mobility and less space. To compare average per game scenarios between positions we checked that all analysed players did not have significant differences in the minutes played per game. The data which were analysed arose from routine daily monitoring of activities during the season. The local Ethics and Scientific Committee approved the experimental procedures used in this study, and all the players provided informed consent before participating.

***Procedure***

All matches were completed on the same official sport-specific indoor court in similar environmental conditions (court material, temperature, light, facilities…) and during in-season weeks. All players completed a standard 45-minute warm-up comprising dynamic mobility and individual sport-specific skills, such as passing, shooting, dribbling, and playing a small-sided game. Although the players were continuously monitored throughout the warm-ups and total match time, we only analysed data from when players were competing on court. We removed all resting data that was collected after substitutions and between periods.

Each player wore the same micro-technology positioning system device (81 × 45 × 15 mm, 70 g) throughout to reduce potential inter-unit variability [19]. The WIMU PRO™ units are equipped with four 3D accelerometers (full-scale output ranges are ± 16 g, ± 16 g, ± 32 g, ± 400 g, at 100 Hz sample frequency), three gyroscopes (8000º/s full-scale output range, at 100 Hz sample frequency), a 3D magnetometer (100 Hz sample frequency), a global positioning system (10 Hz sample frequency), and a local positioning system with UWB technology (18 Hz sample frequency). For better signal emission and reception, six UWB antennas were installed on the rink hockey court to form a hexagon (with a sampling frequency of 18 Hz for the positioning data). Recently, the WIMU PRO™ system presented a high intra-class correlation coefficient value for the x-coordinate (0.65), a very high value for the y-coordinate (0.85), and a good percentage technical measurement error of 2.18% [20].

We included four physical demand parameters to describe the MDS and distribution of match activities. These included the following: distance travelled in meters (DT; m); high-speed skating; distance covered >18 km/h, in meters (HSS >18 km·h−1; m); number of high-intensity accelerations (ACC; >2 m·s−2; count); and number of high-intensity decelerations (DEC; >2 m·s−2; count). All these variables were chosen for two reasons: first, they were the ones most commonly used in other descriptive studies of competition loads in indoor sport research, and the thresholds used were the ones most commonly used in other external load research studies on rink hockey [1,2,4,8], which allowed us to compare our results with previous literature, and second, it is a starting point in this kind of literature for further research on both variables and thresholds. After each match, data from the local positioning system were downloaded and extracted using the manufacturer's software (SPRO™, Realtrack Systems SL, version 977). The software provided instantaneous raw data as a rolling average for each variable and player over 30 s epochs. This specific epoch was chosen because it has already been used in previous research [5,15], and could therefore be used to compare common average physical demands during competition.

We extracted the MDS data from the rolling average data for each player, variable, and match; and computed the distribution of the relative physical activities using a two-step process for each player and variable [9,15]. At first, we determined an individual reference value (100% MDS reference value) from the mean of the top three observations per player using the 18 matches sample. That top three observations mean (instead of taking the maximal MDS recorded) had the main goal of avoiding any extreme value that was real in competition (because it was recorded) although it was too unrealistic to happen almost every match, whereas to smooth possible outliers. This is the reason why in the results section, some 30 s scenarios are above 100% of the individual MDS. These individual reference values are presented in Table 8 and compared with the mean MDS of all matches. In the second step, we re-analysed all matches searching all the 30 s scenarios in the rolling average data, transforming the absolute values to relative ones using the maximal reference values likewise in internal load studies the heart rate is expressed through relative values related to the individual's maximal heart rate. Thereafter, we established 10% buckets, counting the number of scenarios in each bucket. The final output was the total number of scenarios per each bucket, player, and variable. All the previous procedures are summarized in Figure 7.

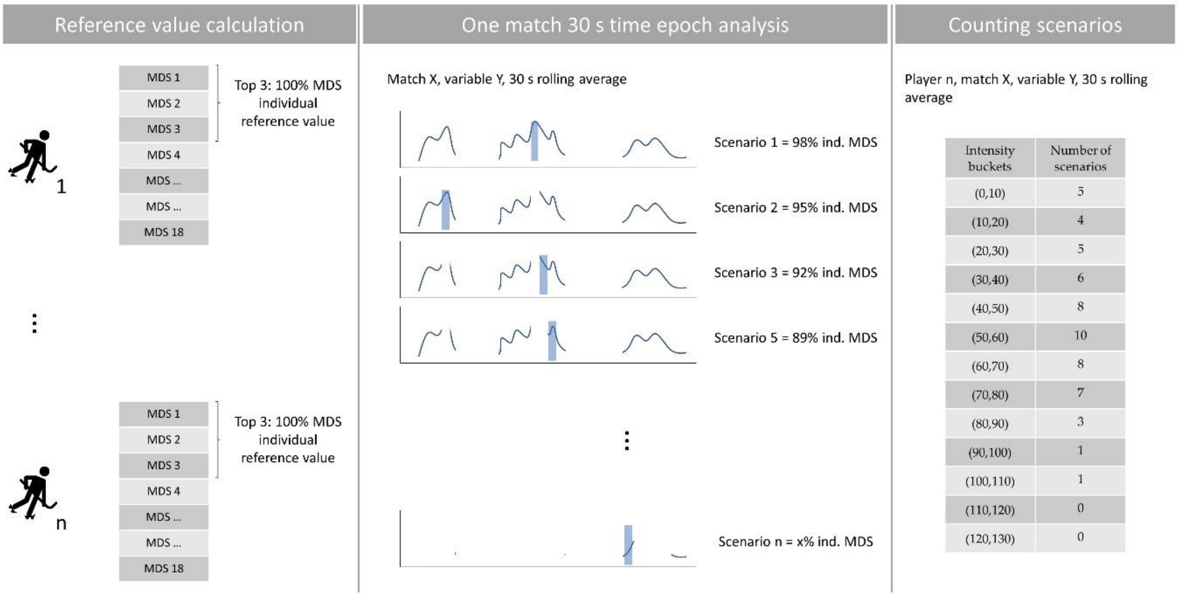


*Figure 7. Brief schematic representation of methodological procedures used to calculate: the individual reference values (left panel), all the scenarios in one match (central panel), and how the scenarios are counted (right panel). Abbreviations—MDS: most demanding scenario.*

*Table 8. Individual reference of the most demanding scenario values for each player extracted from all the games analysed, with the overall means, by position, in 30 s time epochs.*

| | | **DT (m)** | | **HSS (m)** | | **ACC (count)** | | **DEC (count)** | |
|---|---|---|---|---|---|---|---|---|---|
| Position | Player | Top 3 | all | Top 3 | all | Top 3 | all | Top 3 | all |
| Exterior | P1 | 126 | 119 | 62.7 | 49.5 | 6.67 | 5.83 | 7.00 | 5.83 |
| Exterior | P2 | 145 | 134 | 88.2 | 70.4 | 8.00 | 6.72 | 8.00 | 6.67 |
| Exterior | P3 | 142 | 132 | 81.2 | 65.1 | 6.67 | 6.00 | 6.00 | 5.50 |
| Exterior | P4 | 137 | 126 | 73.0 | 57.5 | 8.00 | 6.56 | 7.33 | 6.00 |
| Exterior | P5 | 147 | 132 | 93.7 | 67.7 | 6.33 | 5.44 | 6.00 | 5.00 |
| Exterior | P6 | 122 | 122 | 51.2 | 51.2 | 6.00 | 6.00 | 6.67 | 6.67 |
| Exterior | P7 | 137 | 124 | 77.3 | 55.0 | 6.67 | 5.89 | 6.33 | 5.67 |
| | mean | 136 | 127 | 75.3 | 59.5 | 6.90 | 6.06 | 6.76 | 5.90 |
| | SD | 9.46 | 5.79 | 14.6 | 5.25 | 0.79 | 0.44 | 0.74 | 0.61 |
| Interior | P8 | 136 | 124 | 71.2 | 54.2 | 7.33 | 6.61 | 7.33 | 6.11 |
| Interior | P9 | 132 | 126 | 76.0 | 60.5 | 7.67 | 6.50 | 7.33 | 6.06 |
| | mean | 134 | 125 | 73.6 | 57.4 | 7.50 | 6.56 | 7.33 | 6.09 |
| | SD | 2.69 | 1.53 | 3.42 | 4.44 | 0.24 | 0.08 | 0.00 | 0.03 |

*Note. Data shows mean of the top 3 MDS results for each player with the overall means and SD by position. Abbreviations: ACC, high-intensity accelerations; DEC, high-intensity decelerations; DT, distance travelled; HSS, high-speed skating; MDS, most demanding scenarios; SD, standard deviations.*

### *Statistical analysis*

All statistical analyses were conducted with RStudio version 1.3.1093 (RStudio, Inc.). MDS descriptive data and the number of scenarios per bucket are reported as means ± standard deviations. Sample size analysis was not conducted due to the use of the bootstrap method approach and its assumptions about sample size (bootstrap is a suitable method when the sample size is small) [21]. We conducted an exploratory analysis using boxplots to identify possible outliers of the data. To assess the differences between positions, we used a bootstrap confidence interval approach for MDS and the number of scenarios per bucket [21,22]. A re-sampling model, with 2,000 bootstrap samples and a 95% bias-corrected and accelerated method, was used to calculate the confidence intervals of *t*-test values for each variable. This established the null hypothesis, that there were no differences between positions, and the mean difference between positions was computed and presented as standardised differences (Cohen's *d*). Thresholds for standardised differences were <0.20) for trivial, 0.20–0.59 for small; 0.60–1.19 for moderate, 1.20–1.99 for large, and >2.0 for very large [23]. All reported p-values reflect the likelihoods of observing the absolute effect sizes assuming a true null hypothesis of zero difference [24]. Differences are presented with Cohen's *d* for the effect size and their corresponding 95% confidence intervals.

## RESULTS

Table 9 summarises the descriptive results for the MDS, and Figure 8 shows the hypothesis test results for the MDS. Interiors had greater ACC with significant but small effect sizes.

*Table 9. Most demanding scenarios descriptive results by variable and position.*

| Epoch | Variable | Exterior | | | Interior | | |
|---|---|---|---|---|---|---|---|
| 30 s | DT (m) | 127 | ± | 9.28 | 125 | ± | 6.23 |
| | HSS (m) | 60.5 | ± | 14.3 | 57.2 | ± | 10.4 |
| | ACC (count) | 6.07 | ± | 0.87 | 6.56 | ± | 0.75 |
| | DEC (count) | 5.81 | ± | 0.89 | 6.09 | ± | 0.90 |

*Note. Data show means ± standard deviations. Abbreviations: ACC, high-intensity accelerations; DEC, high-intensity decelerations; DT, distance travelled; HSS, high-speed skating; MDS, most demanding scenarios.*

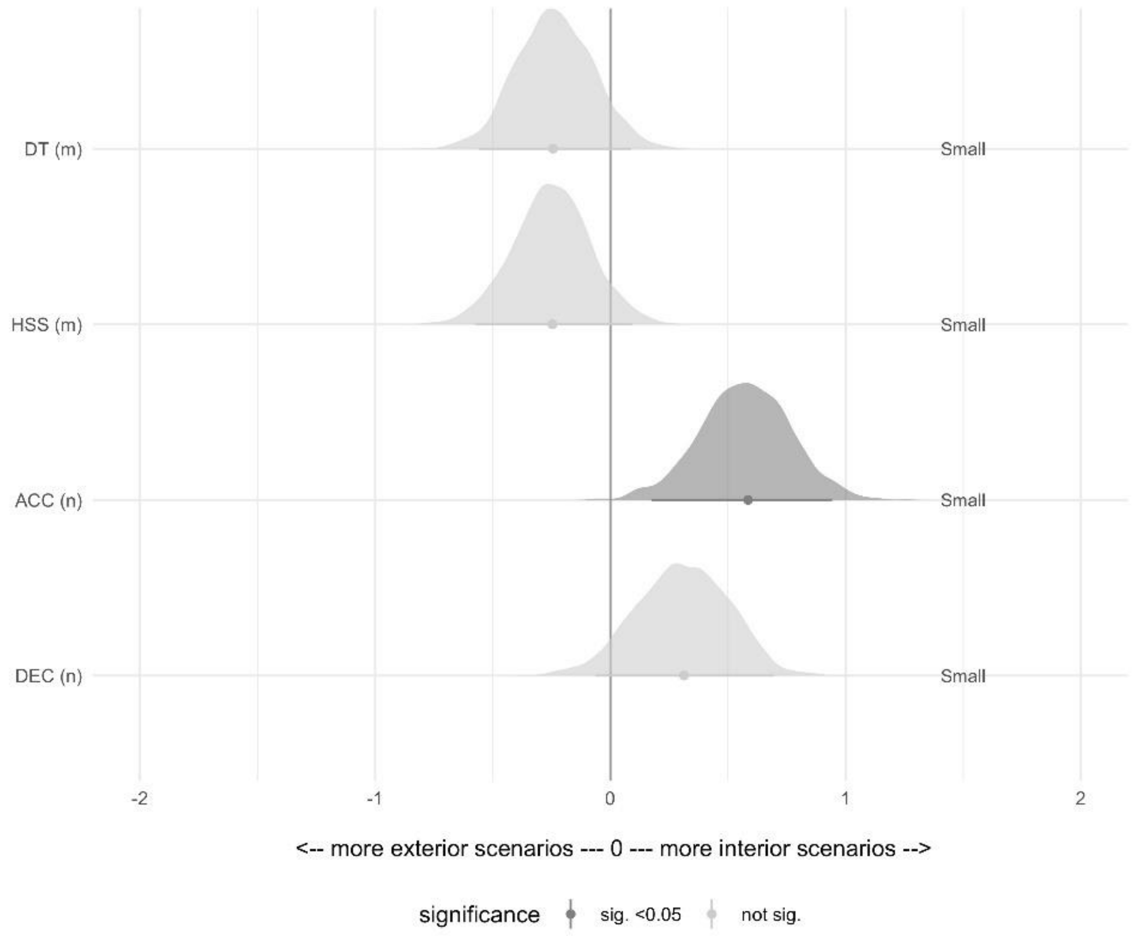


*Figure 8. Pairwise Cohen's d differences in the most demanding scenarios (time epoch 30 s) of a match by playing position for each variable. The significant different variables (high-intensity accelerations) are shown in dark grey, and the non-significant (distance travelled, high speed-skating and high-intensity decelerations) in light grey. Abbreviations—ACC: high-intensity accelerations; DEC: high-intensity decelerations; DT: distance travelled; HSS: high-speed skating; MDS: most demanding scenarios.*

Figure 9 and Table 10 show the descriptive results for the number of scenarios per bucket and variable per match. The DT variable had a greater number of repetitions in the central area of the buckets (between 60%–70% and 70%–80%); the HSS variable had a repetition peak in the first buckets; and the ACC and DEC variables had the greatest number of the scenarios between the 10% and 40% buckets.

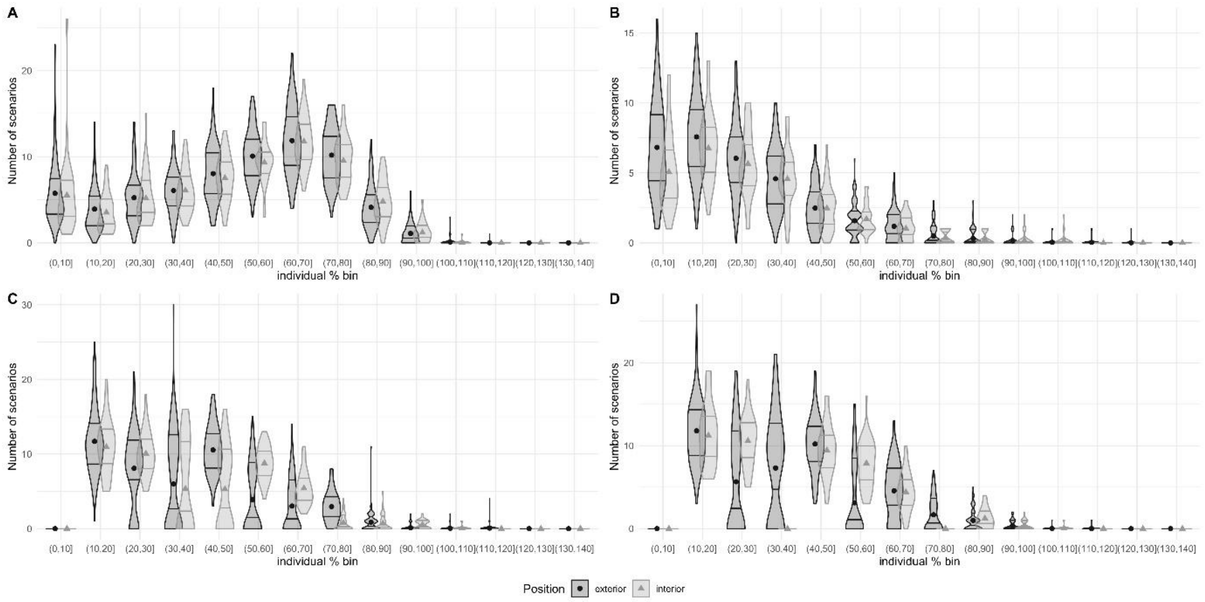

*Figure 9. A graphical descriptive number of 30 s scenarios (mean, quartile 1 and quartile 3) in a match for each intensity bucket for each variable. Exterior players are shown in dark grey and interior players in light grey. A: distance travelled; B: high-speed skating; C: high-intensity accelerations; D: high-intensity decelerations.*

*Table 10. Descriptive results of the repetitions number of 30 s scenarios by interior and exterior players for each bucket and variable per match.*

| Position | Bucket | DT | HSS | ACC | DEC |
|---|---|---|---|---|---|
| | (0,10) | 5.53 ± 4.48 | 5.06 ± 2.70 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| | (10,20) | 3.53 ± 2.14 | 6.76 ± 2.40 | 10.9 ± 3.58 | 11.8 ± 4.01 |
| | (20,30) | 5.18 ± 2.94 | 5.65 ± 2.37 | 10.1 ± 2.89 | 5.66 ± 6.02 |
| | (30,40) | 6.09 ± 2.47 | 4.56 ± 2.09 | 5.35 ± 6.11 | 7.30 ± 6.24 |
| | (40,50) | 7.53 ± 2.64 | 2.47 ± 1.58 | 5.29 ± 5.39 | 10.2 ± 3.20 |
| | (50,60) | 9.32 ± 2.38 | 1.71 ± 1.06 | 8.76 ± 2.22 | 3.12 ± 4.57 |
| Interior | (60,70) | 11.8 ± 2.86 | 1.03 ± 0.90 | 5.41 ± 2.23 | 4.57 ± 3.28 |
| | (70,80) | 9.53 ± 2.68 | 0.35 ± 0.49 | 0.76 ± 1.10 | 1.68 ± 2.00 |
| | (80,90) | 4.79 ± 2.46 | 0.26 ± 0.45 | 0.71 ± 1.14 | 0.99 ± 1.19 |
| | (90,100) | 1.21 ± 1.15 | 0.18 ± 0.46 | 0.53 ± 0.61 | 0.38 ± 0.63 |
| | (100,110) | 0.06 ± 0.24 | 0.12 ± 0.41 | 0.09 ± 0.29 | 0.02 ± 0.14 |
| | (110,120) | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.02 ± 0.14 |
| | (120,130) | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| | (0,10) | 5.75 ± 3.45 | 6.82 ± 3.23 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| | (10,20) | 3.92 ± 2.58 | 7.57 ± 2.86 | 11.7 ± 4.38 | 11.2 ± 3.76 |
| | (20,30) | 5.24 ± 2.89 | 6.04 ± 2.53 | 8.09 ± 5.03 | 10.6 ± 3.08 |
| | (30,40) | 6.07 ± 2.64 | 4.58 ± 2.18 | 5.98 ± 6.46 | 0.00 ± 0.00 |
| | (40,50) | 8.04 ± 3.22 | 2.49 ± 1.64 | 10.5 ± 3.15 | 9.44 ± 3.10 |
| | (50,60) | 10.1 ± 2.99 | 1.58 ± 1.19 | 3.90 ± 4.55 | 7.88 ± 2.83 |
| Exterior | (60,70) | 11.9 ± 3.86 | 1.18 ± 1.09 | 3.03 ± 3.47 | 4.41 ± 2.31 |
| | (70,80) | 10.2 ± 3.16 | 0.49 ± 0.74 | 2.94 ± 2.02 | 0.00 ± 0.00 |
| | (80,90) | 4.12 ± 2.51 | 0.31 ± 0.56 | 0.87 ± 1.30 | 1.24 ± 1.18 |
| | (90,100) | 1.10 ± 1.24 | 0.13 ± 0.37 | 0.13 ± 0.37 | 0.32 ± 0.53 |
| | (100,110) | 0.10 ± 0.38 | 0.04 ± 0.19 | 0.05 ± 0.25 | 0.06 ± 0.24 |
| | (110,120) | 0.01 ± 0.10 | 0.04 ± 0.19 | 0.08 ± 0.43 | 0.00 ± 0.00 |
| | (120,130) | 0.00 ± 0.00 | 0.01 ± 0.10 | 0.00 ± 0.00 | 0.00 ± 0.00 |

*Note. Data shown means ± standard deviations. Abbreviations—ACC: high-intensity accelerations; DEC: high-intensity decelerations; DT: distance travelled; HSS: high-speed skating*

Standardised differences (Cohen's d) and 95% confidence intervals between playing positions are presented in the Figure 10 for all variables and buckets. Exterior players did significantly more scenario repetitions in some buckets for the HSS variable, but with a small effect size. By contrast, both interiors and exteriors showed significant moderate differences in repetition scenarios for the ACC and DEC variables in different buckets and in different and unclear directions.

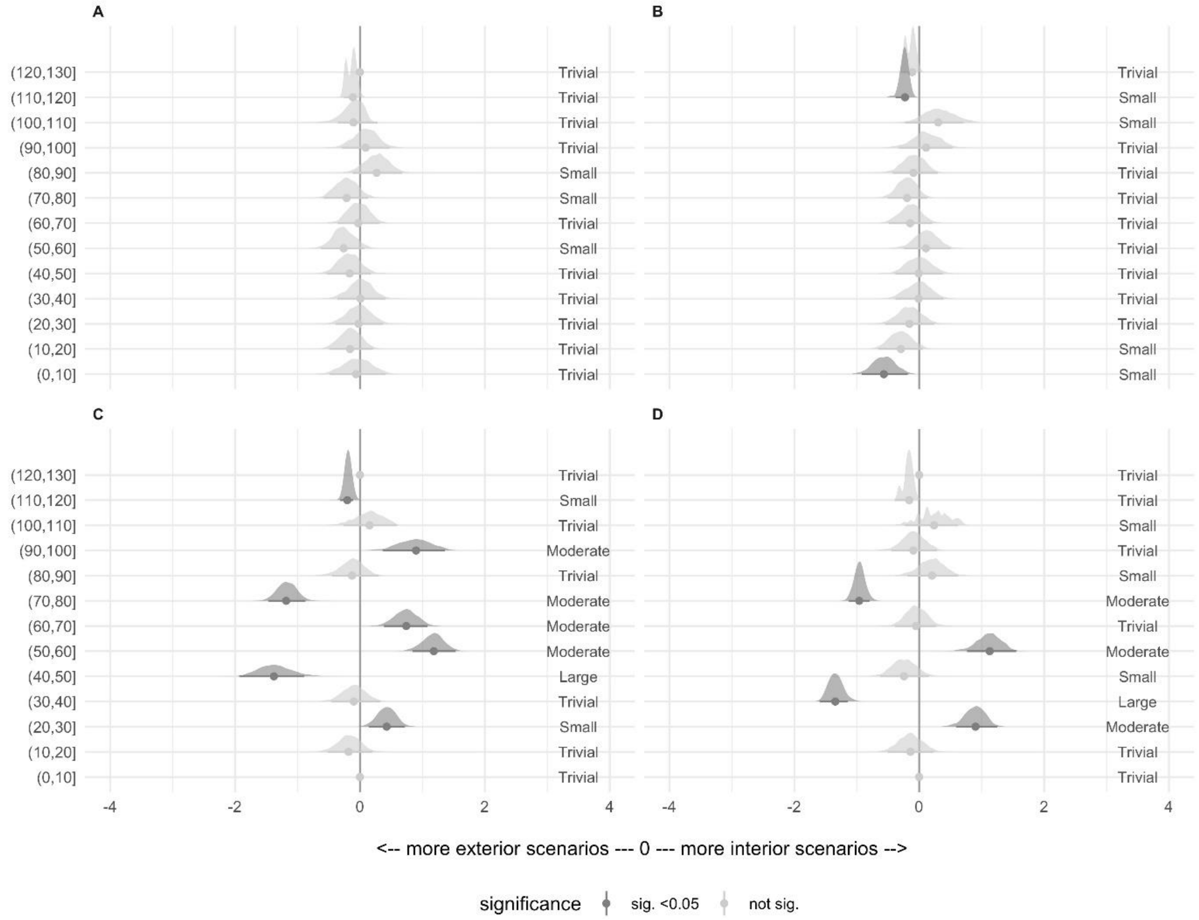


*Figure 10. Pairwise Cohen's d differences between positions for each match bucket per variable per 30 s. The buckets with significant differences between positions are in dark grey, and the non-significant differences are in light grey. A: distance travelled; B: high-speed skating; C: high-intensity accelerations; D: high-intensity decelerations.*

## Discussion

The present study aimed to quantify and assess differences between playing positions in terms of the MDS in official matches. In addition, it aimed to quantify and assess the differences between playing positions in the repetition of different intensity scenarios relative to the individually MDS. We found that the MDS demands during elite competition, although small to trivial, differed by player position in the ACC variable. In addition, rink hockey players were found to be exposed to different intensity 30 s scenarios that repeated more than once depending on their intensity and the metric analysed; exterior players did significantly more scenario repetitions in some buckets for the HSS variable, but with a small effect size.

***Quantification of the MDS and the differences between positions***

A major finding of this study was the quantification of peak physical demand, understood as the MDS in competition. The activity profile described in the current investigation and elsewhere [5,6] seems much more demanding than reported in a previous rink hockey study [2] that used average measures instead of rolling average epochs. The latter study found that players averaged 129–132 $m \cdot min^{-1}$ for DT, 24.8–26.8 $m \cdot min^{-1}$ for HSS, 4.8 $count \cdot min^{-1}$ for ACC, and 4.5 $count \cdot min^{-1}$ for DEC. Our investigation indicates that rink hockey had higher MDS values in 30 s time epochs compared to all these averages. In accordance with Vázquez-Guerrero et al. [6], our results improve coaches and sport scientists' understanding of the demands of competition, and will help them design more accurate training drills that achieve peak demands and mitigate the risk of injury. Individual training sessions can be an example of how MDS knowledge can be useful. The creation of tasks that simulate different MDS that can be found in matches using different variables can be another way (obviously, not the only one) to schedule and prepare exercises. This enhances the training sessions.

After comparing the peak and average demands of rink hockey, it could be interesting to perform comparisons with other team sports to examine rink hockey in its wider context. The peak demands in rink hockey were higher than in outdoor sports like soccer [11] and rugby [12], except for DT and HSS, where the demands were similar. For indoor sports like basketball [6,13] and futsal [14] we found peak demands in rink hockey to be greater for all the analysed metrics, except for ACC and DEC in futsal, where the demands were similar. In comparison with outdoor sports, the results of indoor sports are more interesting because of the significant differences in the number of players or the space compared with outdoor sports. As reported by Fernández et al. [1], the use of roller skates and fences in rink hockey could account for the higher average values and peak demands of DT and HSS compared to basketball and futsal.
Finally, we found that the MDS data are position-dependent for the ACC metric, albeit with small magnitudes of difference. Interior players performed a greater number of accelerations (from 5.81 to 6.09 ACC per 30s scenario between interior and exterior players) in the MDS of matches. This significant difference may be relevant when prescribing a training programme,

despite the low magnitude of effect. As with other indoor sports, the inherent requirements of each position in games and a team's playing model could explain these results [25]; there could be less space for interior players in rink hockey, so they may require more reception and rebounding movements, or press after losing possession of the ball in another court, defend in own court, or support in spaces with high player density by doing more change-of-directions, stops, and other sharp movements. These difference have not been reported for the average demands of competition, where the only published research to date found no significant differences between positions in absolute or relative variables because of the fast and dynamic nature of the sport studied [2]. Therefore, it may be that no significant differences exist in accumulated external load between exteriors and interiors, but that these demands are sensitive to the player's position during the MDS of competition but in a small magnitude. This information can help coaches improve their training tasks. With a range of options as large as adding conditioning blocks focused on the specific demands of specific positions (i.e., interior players), up to changing rules, number of players or spaces in small-sided games (i.e., reducing the space of the court as literature about small-sided games demonstrates that is a variable that highlights the ACC and DEC demands [26]).

***Quantification of scenarios' repetition relative to individual MDS and the differences between positions***

To assess repetition, we divided the scenarios by relative intensity of an individual MDS. The resulting scenarios were categorised as low demand (<40% of individual MDS), moderate demand (40%–80%, MDS), high demand (80%–90%, MDS), and very high demand (>90%, MDS), according to previously published criteria [16]. This allowed us to determine the repetition of 30 s scenarios with different levels, depending on the intensity and the variable under investigation. Similar to our results, research regarding official futsal matches [15] concluded that high-demand and very high-demand scenarios occurred more than once in a variable-dependent manner. Results from basketball matches [16] indicates that scenarios recur across all intensities to different extents. Finally, research regarding rugby league and Australian rules football [17,18] showed that scenarios of a moderate relative intensity recurred most during official matches.

Our methodology encourages a practical in-field use by counting the number of scenarios in each bucket across the intensity spectrum. This could be useful for providing coaches with reference data on the number of repetitions to programme into training drills to under- or over-stimulate the demands of the competition (e.g., doing 6 reps of a 30 s drill at approximately 70%–80% of an individual MDS DT will under-stimulate the match volume requirements in terms of scenario repetition). Volume-related variables (DT) had the greatest proportion of scenarios between 50% and 90% of the individual MDS, with a peak in the 60%–70% bucket. The higher the intensity criterion of the studied metric, the greater the proportion of scenarios that seem to accumulate in lower buckets. For example, the peak scenario repetition was in the 10%–40% bucket for ACC and DEC compared to the 10%–20% bucket for the HSS. So, in the analysed team, moderate- to high-demand scenarios were repeated most for volume-related variables, while low- to moderate-demand scenarios were repeated most for intensity-related variables.

When comparing the distribution of different scenarios, variables, and playing position, we observed multiple significant differences between exterior and interior players. Like the MDS results, our data revealed that exterior and interior players tend to be exposed to almost the same physical demands in low, moderately high, and very high-intensity buckets for the DT and HSS variables (except in two buckets of HSS). As with the MDS, one explanation could be that exterior and interior players had a fast, dynamic, and substantial exchange of positions in certain moments of matches. By contrast, interior and exterior players had stochastic differences in the number of scenario repetitions in ACC and DEC metrics only in most of the buckets. Again, as was the case for the MDS, interior players tend to perform more short actions in a confined space, which influences the number of moderate- and high-demand repetitions between interior and exterior players; but this tactical behaviour (short, fast, and sharp actions) does not affect in a clear way the results of our study. It could be that the study of different time epochs is necessary to find some more clear differences between player positions. To the best of our knowledge, this is the first study in rink hockey to consider playing positions when examining how match physical activities are distributed in relation to the MDS. Our results show that the distribution of physical activities seems not to be position-dependent during official competition by professional rink hockey players.

**LIMITATIONS**

This research has some limitations. First, we collected data from only one professional team, resulting in a small, but exclusive, international, and professional sample. Second, we only examined the MDS and physical activity distribution relative to peak demands for 30 s. As shorter and longer time periods are also possible during a match, using 60, 120, 180, and 300 s epochs might yield more useful data. Third, this is a field pioneering research on the repetition of different intensity scenarios. Consequently, some procedures, such as calculating individual reference values, using intensity buckets, or using fixed time epochs, may require more investigation to find the best method that would allow a more accurate description of the competition. The distribution of preparatory activities regarding the MDS of a match during different training sessions (1, 2, 3, and 4 days prior to competition) should be considered in future research, as well as methodology improvements, to optimize the performance of individual players and teams.

## CONCLUSIONS

In conclusion, this research shows that rink hockey matches have higher 30 s peak demands than the averages reported in other research [2], and that these peak demands are position-dependent, with greater ACC values for interior players. Rink hockey matches also appear to include multiple exposures to (very) high-demand scenarios that are close to the peak physical demands of a match. We detected different scenario repetition distributions across all intensity buckets among the variables studied. Therefore, coaches and sport science professionals should consider the repetition of scenarios during training sessions based on the results. On individual interventions for example, interior players may also need a training stimulus increase for the ACC metric. Depending on the goal of training and the context within the season, adding more repetitions or a higher relative intensity based on the individual MDS may be appropriate.

From a practical perspective, the repetition of scenarios application allows coaches to program different intensity sets of fixed time epochs (which must be prescribed using the individual MDS reference) and determine whether the player is performing a volume below, equal, or above match demands. Moreover, this methodology allows to control the external load demands of the weekly training cycle, by using different intensity buckets (e.g., low, moderate, and intense) to determine which training session causes a greater repetition of intense scenarios, and whether it is above, equal, or below match demands. Alongside the lack of previous literature on this topic, our findings should stimulate the external load control future research, specifically, in rink hockey.

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## 10. Estudi 4

Aquest estudi es correspon amb el següent article:

Load demands in small-sided games in elite rink hockey External and internal load demands in small-sided games according to standard training games in elite rink hockey
D. Fernández, G. Carmona, F. García, J.A. Cadefau, L. Martín.
Sportperfsci. 2023 Mar;187(1).

**HEADLINE**

Small-sided games (SSGs) are useful tasks in modern training methodology, and a growth trend in both practical and scientific fields[1]. In outdoor sports like soccer, the evidence is clear regarding the manipulation of pitch area. The larger the absolute and relative space, the more external load (EL) and internal load (IL) demands[1]; only accelerations and decelerations were void of a significant relationship respect the pitch area[2,3]. In rink hockey, the relationship between space and EL and IL is unknown.

**AIMS**

Therefore, the aim of our study was to quantify and assess differences in EL and IL between a standard training game format of 40 x 20 m versus a largely implemented training SSG drill in a format of 20 x 20 m training game.

**DESIGN AND METHODS**

***Design***

A retrospective observational study was carried out for the 2021-2022 season. A non-experimental descriptive method was used to identify the EL and IL demands in two different training game formats in this rink hockey professional team. EL was measured by an ultra-wide band (UWB) electronic performance tracking system (WIMU PRO$^{TM}$, Realtrack Systems, Almeria, Spain) and IL was measured using heart rate monitoring; all the data collected was later presented expressing the tasks demands relative to time ($m \cdot min^{-1}$, $n \cdot min^{-1}$ or $sec \cdot min^{-1}$). Data were collected throughout 17 weeks of in-season.

***Athletes***

Elite male professional rink hockey players (n = 8, age: 28.5 ± 5.07 years, weight: 78.6 ± 4.13 kg, height: 180.8 ± 4.13 cm, all measurements mean ± standard deviation) participated voluntarily in the study, whereas the goalkeepers were excluded. At the time of the study, the team was holding between 4 and 5 practice sessions a week (between 1 and 1.5 hours) and was playing 1 or 2 matches a week. The data analyzed came from the daily player monitoring, in which player activities in court were routinely measured throughout all season. The experimental procedures used in this study were approved by the local Ethics and Scientific Committee (The Ethics Committee for clinical research of the Catalan Sports Council, 29/CEICGC/2020) and all the players signed an informed consent form before participating.

***Methodology***

To compare different tasks, the activity profile of the players was monitored during each training session. Each player wore the same positioning system micro-technology device (81 × 45 × 15 mm, 70 g) throughout to reduce potential inter-unit variability[4]. The WIMU PRO™ units are equipped with four 3D accelerometers (full-scale output ranges are ± 16 g, ± 16 g, ± 32 g, ± 400 g, at 100 Hz sample frequency), three gyroscopes (8000º/s full-scale output range, at 100 Hz sample frequency), a 3D magnetometer (100 Hz sample frequency), a global positioning system (10 Hz sample frequency), and a local positioning system with UWB technology (18 Hz sample frequency). For better signal emission and reception, installation on the rink hockey court comprised of six UWB antennas located to form a hexagon (sampling frequency of 18 Hz for the positioning data). The WIMU PRO™ system has been evidenced to have a high intra-class correlation coefficient value for the x-coordinate (0.65), a very high value for the y-coordinate (0.85), and a good percentage technical measurement error of 2.18%[5]. For IL players wore a chest-worn heart rate monitor (Garmin HRM3-SS, Garmin Ltd., Olathe, USA). The heart rate monitor data was sent to WIMU PRO™, recorded at 18 Hz sample frequency, and treated together with the EL data.

The most standardized training game formats during the season were used to for the analysis. For instance, both were 4 vs. 4 players with goalkeepers in both teams. A 40 x 20 training game (TG40x20) was one of the analyzed tasks (area: 100 $m^2$ per player), and a 20 x 20 training game (TG20x20) was the other analyzed task (area: 50 $m^2$ per player). Both training games included official rules, but in the TG20x20 one of the sides were without fence (Figure 11) and every time the ball went out of bounds, a coach would put a neutral new ball in the court with the aim of avoiding stoppages. A total of 371 individual records (n = 329 for TG40x20 and n = 42 for TG20x20) were obtained. Analyzed game formats were conducted in the final part of the sessions. As the sample size reveals, the TG40x20 was a training game format that was used in a vast majority of the training sessions, and the TG20x20 was a training game format only used once in each microcycle.

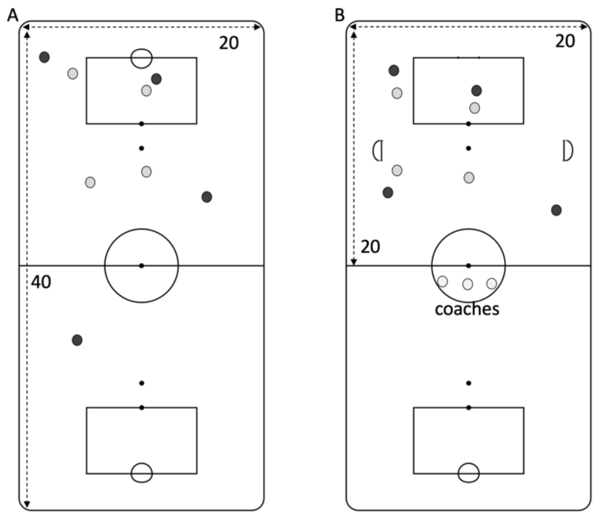


*Figure 11. Court diagram of the training games. A: 40 x 20 training game (TG40x20), and B: 20 x 20 training game (TG20x20).*

The EL recorded variables were distance covered ($m \cdot min^{-1}$), distance covered at high-speed skating (>18 $km \cdot h^{-1}$, $m \cdot min^{-1}$), number of high-intensity accelerations (> 2 $m \cdot s^{-2}$, $n \cdot min^{-1}$), and the number of high-intensity decelerations (> 2 $m \cdot s^{-2}$, $n \cdot min^{-1}$). The IL recorded variable was the time spent above 90% of maximal heart rate (HRmax) ($sec \cdot min^{-1}$). All the EL intensity thresholds were established based on previous studies[6]. As Abad et al[7] recommended in their research, we used the highest individual heart rate registered during all training and friendly games between August and December of 2021, as their methodology revealed its efficiency being comparable to maximal tests to calculate individual maximal heart rate.

***Statistical analysis***

All statistical analyses were conducted with RStudio version 1.4.1103 (RStudio, Inc.). Descriptive results were reported as mean ± standard deviation. The assumptions for homogeneity of variance (Levene's test) and for normality Shapiro–Wilk test were violated. As a result, a bootstrap confidence interval (CI) approach was used to perform the hypothesis test to assess the differences between training games format[8–10]. A residual resampling model with 5,000 bootstrap samples and 95% bias-corrected and accelerated method (BCa 95% CI) was used to calculate the CI of Cohen's D for each variable[11]. Thresholds for effect size (ES) statistics were (ES <0.20), trivial; (0.20 < ES <0.59), small; (0.60 < ES <1.19), moderate; (1.20 < ES <1.99), large; and (ES > 2.0), very large[12].

## RESULTS

The descriptive results of the EL and IL variables from the two training games formats analyzed are displayed below in Table 11. The inferential analysis with bootstrapped resampling is presented in Figure 12. Results revealed that only distance covered ($p < 0.001$; ES 95%CI = 1.95-2.60), and high-speed skating ($p < 0.001$; ES 95%CI = 2.47-2.92) had significant differences between the two training game formats.

*Table 11. Descriptive results (mean ± standard deviation) of studied variables in different training games formats.*

| | 40 x 20 Training Game | 20 x 20 Training Game |
|---|---|---|
| Distance covered (m·min$^{-1}$) | 141 ± 12.8 | 112 ± 12.0 |
| High-speed skating (m·min$^{-1}$) | 25.8 ± 8.61 | 3.65 ± 3.10 |
| High-intensity Accelerations (n·min$^{-1}$) | 4.63 ± 0.90 | 4.88 ± 1.26 |
| High-intensity Decelerations (n·min$^{-1}$) | 3.51 ± 0.86 | 3.63 ± 1.04 |
| Time >90% HRmax (sec·min$^{-1}$) | 16.5 ± 14.4 | 12.5 ± 14.9 |

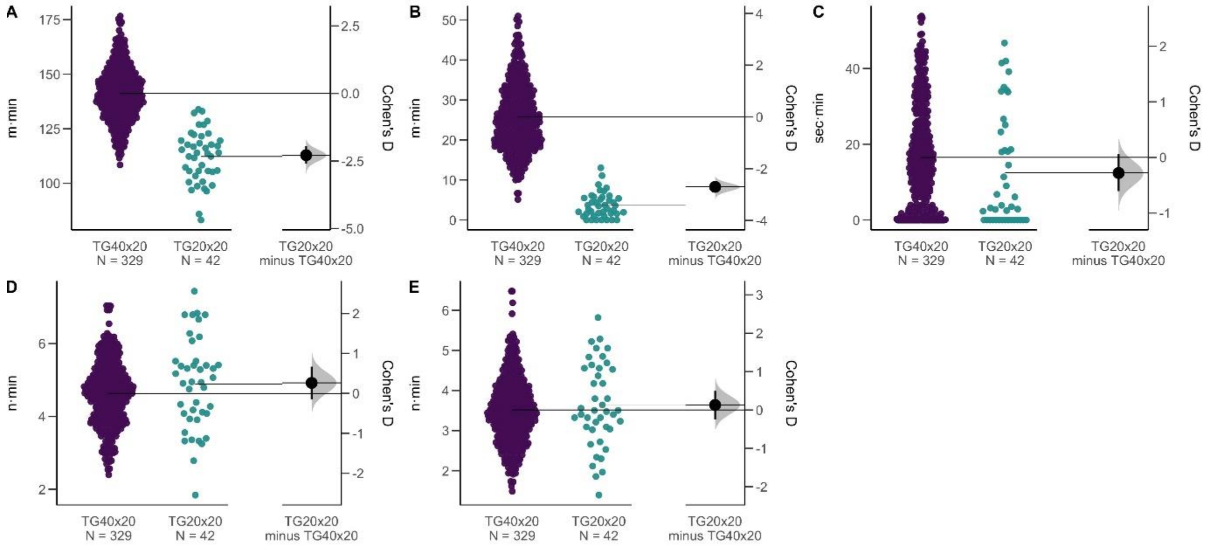


*Figure 12. Distribution and Cohen's D differences between game formats in all the studied variables. A: Distance covered (m·min-1), B: High-speed skating (m·min-1), C: Time >90% HRmax (sec·min-1), D: High-intensity Accelerations (n·min-1) and E: High-intensity Decelerations (n·min-1). Note. TG40x20: Training game 40x20; TG20x20: Training game 20x20.*

**DISCUSSION**

The aim of this research was to quantify and assess differences in EL and IL between a standard training game (TG40x20) versus a SSG training drill (TG20x20). To the best of our knowledge, this is the first study to compare training game drills in rink hockey. Our results revealed large significant differences in distance covered and high-speed skating between tasks; but no differences in the number of accelerations, decelerations and the time spent above 90% of HRmax.

The absolute and the relative space reduction of the pitch size could be the principal reason that players cover less meters, and particularly at higher speeds. This could be due to the difficulty in achieving and maintaining high velocities in a smaller space with the same number of opponents[1]. Our results are in line with previous research conducted in SSGs and pitch size, either outdoor or indoor sports[1,13,14] where the lesser space used, the lesser the distance covered.

On the other hand, the other studied variables did not reveal significant difference. Results showed that there aren't differences between TG20x20 and TG40x20 in high-intensity accelerations and decelerations, and time spent above 90% of HRmax. Starting with EL metrics, it seems that the space reduction doesn't affect the capacity of the players' high-intensity accelerations and decelerations, which could be due to the relative space used in the TG20x20 that entails a need for the players to perform the same amount of change of directions, reception movements and cuts equal to a normal game. The literature is incongruent in this respect, some studies have shown results in line with a non-reduction of these EL variables in SSGs in relation to a standard game[1], but other research have shown evidence that accelerations and decelerations decrease when the space is reduced[2,3]. The internal load metric analyzed in this research did not reveal any significant difference between the two game formats, despite the space reduction. The IL of the task remained the same level of that of a standard game. Our findings, in conjunction with the EL findings encourages us to conjecture that the maintenance of similar values of high-intensity accelerations and decelerations between TG20x20 and TG40x20, is consistent with IL values. Research in soccer is well-defined in terms of the behaviour of internal load. The majority of studies reporting an increased heart rate, perception of effort and blood lactate concentration response with increased pitch area[15]. Only Kelly & Drust[16] were the exception in that their study failed to find significant differences in heart rate peak between three different SSG formats.

To conclude, this research allows professionals of rink hockey to be cognizant of the effects of reducing the pitch size in a training game drill. It seems that the reduction of the space reduces the distance that players travelled, but yet still allow them to reach the same high-intensity accelerations, decelerations, and time spent above 90% of HRmax. This study's finding allows coaches to know what happens on the court when they manipulate training constraints such as pitch size. Finally, based on the work of Buchheit & Laursen[17], classification of metabolic and neuromuscular load in high intensity interval training, reducing space is a feasible application that concentrates on neuromuscular load.

**PRACTICAL APPLICATIONS**

The findings of this study can be applied by coaching staff working directly with athletes and being mindful of the pitch size and its impact on EL and IL.

- It's interesting to point that the reduction of the space in the analyzed tasks didn't affect the IL intensity response of the players, noting that players had same effort levels doing less EL than in a standard match.
- Based on our findings, the use of the TG20x20 allow players to stimulate the neuromuscular system doing the same amount of high-intensity accelerations and decelerations, with less distance covered.
- Future studies would include increasing the relative pitch area (i.e., 3 vs. 3 in 40x20 meters pitch), as it would be interesting to examine if that would increase the IL response.

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# Capítol 4.

# Discussió i conclusions

# 11. Discussió general

La discussió dels resultats obtinguts en els articles realitzats durant aquesta tesis es pot resumir en els següents punts: com és i que se'n pot extreure del registre de la càrrega externa durant els partits; quines són i perquè les diferencies de càrrega externa entre posicions de joc; quina és la relació en el registre de la càrrega externa i interna durant els entrenaments d'hoquei patins; i finalment, com pot influir l'espai de joc en tasques d'entrenament.

## 11.1. La càrrega externa durant els partits d'hoquei patins

La càrrega externa durant partits oficials va ser estudiada en el primer i tercer article d'aquesta tesi. El primer estudi va ser la primera recerca científica publicada que va quantificar mitjançant dispositius EPTS la càrrega externa total i relativa al minut dels jugadors d'hoquei en competició oficial. D'altra banda, el tercer estudi d'aquesta tesi va quantificar i avaluar els escenaris de màxima exigència en partits oficials; i també va quantificar i avaluar la repetició de diferents escenaris de diferent intensitat respecte a l'escenari de màxima exigència individual.

Primer de tot, contextualitzar les demandes mitjanes que imposa la competició pot ser un exercici interessant per poder comprendre la naturalesa de l'hoquei patins. Els resultats obtinguts en variables absolutes com DT, ACC, DEC o HSS situen clarament l'hoquei en una posició inferior a altres esports d'equip de camp gran, com el futbol (Akenhead et al., 2013; Mallo et al., 2015) i el rugbi (Yamamoto et al., 2017). Aquest resultat és esperable ja que, com altres esports d'interior, l'hoquei té una àrea de joc menor i una durada de partit més curta. L'ús de variables absolutes, com la DT recorreguda durant tot el partit, amaga una característica important dels esports d'interior: les substitucions contínues de jugadors. Per això, en el primer estudi d'aquesta tesis es va proposar també l'ús de valors mitjans relatius, com ara la distància relativa (DT/min), en comptes de valors absoluts. Aquesta pot ser una eina adequada per a la comparació de mètriques de volum de càrrega externa. Comparant amb altres esports d'interior, l'hoquei sobre patins té valors de DT/min més grans que el futbol sala (Barbero Alvarez et al., 2008; Naser et al., 2017), el handbol (Barbero Alvarez et al., 2014) o el bàsquet (Puente et al., 2017). Això podria ser degut a la dificultat d'estar immòbil amb patins i a la menor quantitat d'interrupcions durant el joc, a causa de les tanques al voltant de la pista.

Un altre aspecte clau a l'hora de quantificar la càrrega externa dels partits és la relació entre la forma de desplaçar-se per la pista que tenen els jugadors d'hoquei patins i com això pot afectar les variables registrades. Una de les variables més afectades en aquest cas és el PL, ja que aquesta és sensible a la forma en què es mouen els jugadors i s'ha demostrat que és una variable important per controlar la càrrega mecànica (Reche-Soto et al., 2019). Tècnicament, l'ús de patins en comparació amb córrer no comporta una fase de vol durant el desplaçament, per tant, hi ha menys impacte en l'eix vertical, la qual cosa podria permetre acumular menys PL/min. Com hem esmentat a la introducció, la manca d'informació disponible en la literatura sobre l'hoquei patins fa que no hi hagi evidència científica de que la biomecànica del patinatge difereixi de la carrera en termes de càrrega externa, però aquesta investigació podria ser un primer pas per identificar algunes diferències amb altres esports de carrera. Algunes investigacions (Lacome et al., 2018) suggereixen que la relació entre mesures de velocitat de desplaçament (DT/min) i càrrega mecànica (PL/min) podrien ser una mètrica de la quantitat de força requerida per unitat de desplaçament, utilitzada per avaluar l'eficiència neuromuscular durant els desplaçaments dels jugadors. Els nostres resultats indiquen que aquesta relació pot ser superior en l'hoquei patins que en altres esports de carrera (més distància per càrrega de força), la qual cosa implica una eficiència en el moviment més alta i una càrrega mecànica més baixa.

A part de les demandes totals i les demandes relatives, un pas més en l’anàlisi de la càrrega externa és el registre dels escenaris de màxima exigència. El tercer article d’aquesta tesi va centrar la recerca en aquest tema, i va demostrar que els valors dels escenaris de màxima exigència en totes les variables estudiades, igual que en altres esports (Cunningham et al., 2018; García et al., 2021; Illa et al., 2021; Martín-García, Casamichana, et al., 2018; Rico-González et al., 2021), van ser superiors als valors de les demandes mitjanes estudiades en el primer article de la tesi. Això implica que hi ha moments del partit de durada indeterminada que són més exigents que la mitjana total, i per tant, els entrenadors i preparadors físics han de dissenyar tasques adequades per a preparar als jugadors per afrontar aquestes situacions més demandants.

Finalment, a més de les demandes totals, relatives i els escenaris de màxima exigència; també es van avaluar la repetició d'escenaris de diferent intensitat per analitzar i entendre la carrega externa imposada en els partits d’hoquei patins. Per fer-ho, es van classificar els escenaris depenent de la seva intensitat relativa respecte de l'escenari de màxima exigència individual. Així doncs, es van dividir en escenaris de demanda baixa (<40% de l'escenari de màxima exigència individual), de demanda moderada (40% - 80% de l'escenari de màxima exigència individual), de demanda alta (80% - 90% de l'escenari de màxima exigència individual) i de demanda molt alta (>90% de l'escenari de màxima exigència individual), utilitzant criteris publicats anteriorment en estudis similars en altres esports (García et al., 2022). Això va permetre determinar la freqüència de repetició d'escenaris, en el nostre estudi, de 30 segons de durada i de diferents nivells d'intensitat. Els resultats van demostrar que, en totes les variables estudiades, els escenaris de baixa, moderada i fins i tot alta intensitat es repetien més d'una vegada per partit. De manera similar, en partits oficials de futbol sala (Illa et al., 2020), es va concloure que els escenaris d'alta demanda i de molt alta demanda es van repetir més d'una vegada de manera variable. En partits de bàsquet (García et al., 2022), els resultats van indicar que els escenaris es van repetir també en totes les intensitats. Així doncs, ens trobem que de forma transversal en esports d'equip, i l'hoquei no escapa d'aquesta classificació, existeix més d'un sol escenari d'alta intensitat i els jugadors han de fer front a aquesta realitat amb fases intercalades de menor demanda.

Fins el moment, mai s'havia pogut obtenir dades de referencia respecte les demandes condicionals de càrrega externa que un partit d'hoquei patins comportava. Aquesta primera part de la discussió posa en relleu el fet de que independentment del mètode utilitzat (resultats totals, relatius al minut, escenaris de màxima exigència, o repetició d'escenaris), l'hoquei patins comporta unes demandes elevades en comparació a altres esports d'interior; i que aquestes demandes son variables durant la competició, amb moments de molt alta demanda que es repeteixen més d'una vegada per partit.

## 11.2. Les diferencies entre posicions de joc

Les diferencies entre les posicions de joc és un dels objectius transversals en diferents dels estudis realitzats durant aquesta tesis. Els resultats obtinguts en el primer estudi on es va descriure la càrrega total i relativa de partits d'hoquei patins mostren com no hi va haver diferències entre jugadors exteriors i interiors en totes les mètriques estudiades. Per altra banda, en el tercer estudi es van trobar diferencies d'una mida petita en la variable ACC en els escenaris de màxima exigència i diferencies estocàstiques en variables com ACC i DEC en quant a la repetició d'escenaris.

Així doncs, quan el focus de l’estudi és general, estudiant demandes totals, no es van observar diferències significatives entre les posicions en cap de les variables analitzades. Aquesta troballa resulta interessant, ja que la bibliografia relacionada amb altres esports d’equip indica habitualment que existeixen diferències significatives entre posicions (Luteberget & Spencer, 2016; Vázquez Guerrero, Suarez Arrones, et al., 2018). En l’hoquei patins, la gran mobilitat dels jugadors dins de la pista i la dinàmica dels models de joc actuals poden influir en aquestes posicions d’interior i exterior, fent que siguin intercanviables i poc definides durant els partits. Per altra banda, el tipus d’anàlisi realitzat, pot afectar als resultats, emmascarant dins d’una demanda global accions intermitents que es poden donar diferents segons posicions però que són impossibles de veure en anàlisis de valors totals o relatius durant la durada absoluta d’un partit.

En quant a les diferències entre les posicions dels jugadors en l’anàlisi d’escenaris de màxima exigència, en contrast amb les demandes mitjanes, es va trobar que hi havia un nombre significativament més alt d'ACC en jugadors interiors en comparació amb els exteriors, tot i que amb una mida d'efecte petita. Això pot ser explicat per les característiques específiques de cada posició i pel model de joc de l'equip analitzat, com en altres esports d'equip (Ben Abdelkrim et al., 2007). En concret, els jugadors interiors tenen menys espai per jugar i per tant, poden necessitar fer més moviments per rebre la pilota o desmarcar-se en moment puntuals. A més, també han de ser capaços de pressionar ràpidament després de perdre la possessió, recolzar als companys en zones amb alta densitat de jugadors i estar atents als rebots després de xuts a porteria. Aquesta informació pot ser útil per als entrenadors per a millorar les seves tasques d'entrenament i dissenyar exercicis específics que satisfacin les exigències de cada posició. Algunes opcions podrien ser afegir blocs d'entrenament centrats en les exigències específiques de cada posició, centrar entrenaments individuals en alguna mètrica o adaptar les regles, el nombre de jugadors o els espais de joc de les tasques d'entrenament. Aquest tema serà tractat en el punt 6.3 d'aquesta tesi.

En comparar la distribució de diferents escenaris i variables segons la posició de joc, es van observar múltiples diferències significatives entre els jugadors exteriors i interiors. Igual que els resultats relacionats amb els escenaris de màxima exigència, els resultats obtinguts sobre les repeticions d'escenaris van revelar que els jugadors exteriors i interiors tendeixen a estar exposats a gairebé les mateixes demandes físiques en escenaris d'intensitat baixa, moderada, alta i molt alta per a les variables DT i HSS (excepte en casos puntuals de HSS). Per contra, els jugadors interiors i exteriors van mostrar diferències estocàstiques en el nombre de repeticions d'escenaris en les mètriques d'ACC i DEC. Tot hi que els resultats donen informació sobre com són les demandes de joc, avançant-nos al apartat de limitacions de la tesis, l'explicació més plausible és que aquestes diferencies siguin per les característiques individuals pròpies dels jugadors analitzats, on la mostra és petita en el cas dels jugadors interiors. A part, l'estudi de diferents finestres temporals també és necessari per trobar diferències més clares entre les posicions.

## 11.3. La càrrega externa i interna durant l'entrenament en hoquei patins

Un cop desgranats els descobriments respecte la competició, és igual d'important saber que passa durant les sessions d'entrenament. En aquest cas, el segon estudi va centrar la seva atenció en les sessions d'entrenament d'hoquei patins, amb els següents objectius específics: presentar un enfocament integrador de la dinàmica de la càrrega externa i interna de les sessions d'entrenament específiques a la pista durant una setmana estàndard d'entrenament (una setmana amb un sol partit durant el cap de setmana); avaluar les diferències de càrrega entre tots els entrenaments i partits analitzats; i avaluar la correlació entre les mètriques de càrrega externa i interna analitzades. Els resultats van mostrar una dinàmica de càrrega amb forma "U" invertida en la qual les sessions DP-3 i DP-2 van ser les dues amb la major càrrega externa i interna de la setmana, en comparació amb les altres sessions i lleugerament per sobre del partit. Finalment, pel que fa a l'associació entre les mètriques de càrrega externa i interna, es van observar correlacions altes entre DT, PL i sRPE; correlacions moderades entre ACC, DEC i sRPE; i correlacions baixes entre HSS i sRPE.

Un dels resultats més interessants va ser observar una forma "d'U" invertida en la dinàmica de càrrega, que també s'ha descrit en altres investigacions similars (Akenhead et al., 2016; Los Arcos et al., 2017; Martín-García, Gómez Díaz, et al., 2018; Owen et al., 2017). D'altres estudis van mostrar una disminució progressiva de les mètriques estudiades des de les sessions més allunyades del partit a les més pròximes (Stevens et al., 2017). I per exemple, J. J. Malone et al. (2015) no van trobar diferències entre les sessions d'entrenament DP-4, DP-3 i DP-2. Així doncs, existeixen diferents dinàmiques setmanals d'entrenament descrites a la literatura, però probablement totes tenen una característica en comú: la reducció de càrrega el dia abans del partit.

La corba en forma "d'U" invertida sembla correspondre a una estratègia de reducció de la càrrega imposada (Martín-García, Gómez Díaz, et al., 2018) en què la càrrega externa disminueix a mesura que s'acosta el dia del partit, però que al mateix temps permet als jugadors no tenir l'entrenament amb més volum de càrrega externa de la setmana el primer dia de la setmana. Curiosament, la característica més notable va ser la discordança entre dinàmica setmanal de la càrrega interna respecte de la externa. Per exemple, en la sessió DP-4, la càrrega interna mesurada amb RPE es va mantenir igual d'elevada que en les sessions DP-3 i DP-2. Aquest fet, particular en la setmana d'entrenaments de l'equip analitzat i no extrapolable a altres setmanes d'entrenaments d'altres equips, permet observar la utilitat de la relació entre càrrega externa i interna. Concretament, en la sessió d'entrenament DP-4, es pot observar com la discordança entre una càrrega externa menor que altres entrenaments però una càrrega interna elevada indica que podria existir algun factor extern que augmenta la resposta dels jugadors. En aquest cas, la causa principal podria ser que la sessió d'entrenament de força més llarga de la setmana va ser planificada habitualment abans de l'entrenament DP-4 a pista, cosa que afectaria augmentant l'RPE reportat pels jugadors. Així doncs, fugint del cas concret estudiat, el registre i control de la relació entre càrrega interna i externa pot ajudar a preparadors físics i entrenadors a entendre i gestionar els estímuls presentats als jugadors i la resposta d'aquests.

Els resultats també van ser presentats amb les mètriques de càrrega interna i externa fusionades en un sistema integrat mitjançant puntuacions Z. Aquest tipus d'enfocament de control de càrrega, basat en Gabbett et al. (2017) i Delaney et al. (2018), pot proporcionar una eina de seguiment que situa els jugadors en el continu fitness-fatiga al llarg de les diferents sessions de la setmana. Aquest enfocament utilitza la relació entre les mètriques de càrrega interna i externa per intentar detectar el desacoblament entre variables, és a dir, intentar detectar si en un moment la càrrega externa va tenir una resposta de càrrega interna més baixa o més alta del normal (valors mitjans). En aquest sentit, la els resultats van mostrar que les sessions de DP-4 i DP-1 tendeixen a situar, amb baixa dispersió, els jugadors en una zona de “baixa càrrega interna i externa”, garantint, sobretot en el DP-4 un bon procés de recuperació. Per contra, en les sessions de DP-3 i DP-2, així com en el DP, es van registrar càrregues més elevades. Així doncs, el sistema integrat presentat en el quart estudi pot permetre a entrenadors i preparadors físics estar alerta de respostes individuals inesperades a càrregues imposades pels entrenaments per ajustar les càrregues posteriors i modificar el contingut de l'entrenament. Actualment aquesta eina és utilitzada en la gestió i el control de càrregues d’equips professionals de forma diària (Lacome et al., 2018).

## 11.4. La càrrega externa i interna en les tasques d'hoquei patins

Finalment, a part de la descripció dels partits i dels entrenaments, aquesta tesis ha estudiat l'efecte de variar l'espai de joc en tasques d'entrenament. Concretament, l'objectiu del quart estudi va ser quantificar i avaluar les diferències entre un partit d'entrenament estàndard contra una partit d'entrenament en espai reduït. Els resultats van revelar diferències significatives en la DT i el HSS entre tasques; però no va haver-hi diferències en el nombre d'ACC i DEC i el temps passat per sobre del 90% de la freqüència cardíaca màxima (FCmax).

La reducció d'espai ja sigui absoluta com relativa de la mida del terreny de joc va ser la variable que va marcar la diferencia principal entre les dos tasques. Aquesta podria ser la raó principal per la qual els jugadors van cobrir menys metres, i sobretot van cobrir menys metres a velocitats altes. Literatura revisada avisa que un menor espai de joc augmentaria la dificultat per aconseguir i mantenir altes velocitats degut a l'alta densitat d'obstacles (altres jugadors) i la proximitat de porteries i/o tanques (Sarmento et al., 2018). Els resultats observats també estan en línia amb altres investigacions realitzades en jocs en espai reduït, ja sigui esports a l'aire lliure o coberts (Aguiar et al., 2012; Sarmento et al., 2018; Vazquez Guerrero et al., 2018) on com menys espai s'utilitza, menor és la distància recorreguda.

D'altra banda, les altres variables estudiades no van revelar diferències significatives. Concretament, la reducció d'espai no va afectar la capacitat dels jugadors a realitzar ACC i DEC. Això podria ser degut a l'espai relatiu utilitzat en el joc reduït, i la inherent necessitat dels jugadors a realitzar la mateixa quantitat de canvis de direcció, moviments de recepció i talls que un joc estàndard. La literatura és incongruent en aquest sentit, alguns estudis revisats van mostrar resultats alineats amb els resultats que es van obtenir: no van trobar diferencies en les variables d'ACC i DEC (Sarmento et al., 2018). Per contra, altres investigacions van demostrar que les ACC i DEC van disminuir quan es va reduir l'espai (Castellano & Casamichana, 2013; Hodgson et al., 2014). Tampoc el temps passat per sobre del 90% de la FCmax va revelar cap diferència significativa entre els dos formats de joc. En aquest cas, la literatura que ha estudiat més aquests tipus de variables ha estat la relacionada amb el futbol. La majoria dels estudis van reportar un augment de la freqüència cardíaca, la percepció de l'esforç i la resposta de la concentració de lactat en sang amb un augment de l'àrea de joc (Hill-Haas et al., 2011). Només

Kelly & Drust (2009) no van trobar diferències significatives en el pic de freqüència cardíaca entre tres formats diferents de jocs reduïts.

L'anàlisi realitzat sobre com afecta el canvi de l'espai de joc en tasques realitzades en l'hoquei patins mostra un primer pas en aquesta tesis (com tots els articles presentats en definitiva) sobre com l'ús de dispositius EPTS i el posterior anàlisi d'aquests poden ajudar a entrenadors i preparadors físics a entendre que passa en la pista. És evident que amb la informació obtinguda en el quart article d'aquesta tesis, els entrenadors poden utilitzar els espaïs reduïts per posar el focus de la tasca en les ACC i DEC reduint la resta de variables de càrrega externa. Però igual que sabem que passa actualment en una tasca concreta quan es redueix l'espai de joc, també cal saber que passa quan es varia la densitat de jugadors, quan es varien les normes de joc, quan es limiten els tocs o quan s'utilitzen comodins per jugar.

# 12. Conclusions

Per facilitar la comprensió de les conclusions, aquestes han estat agrupades segons estudi.

## 12.1. Estudi 1

Les demandes físiques del hoquei sobre patins en termes de càrrega externa en un context d'equip d'elit van ser estudiades en aquest article. És important destacar que no hi ha diferències en les variables de càrrega externa mesurades entre les posicions d’exterior i interior en partits oficials.

## 12.2. Estudi 2

Aquesta recerca, presenta un enfocament integratiu de la càrrega externa i interna dels jugadors per monitoritzar l'estat de la forma física i la fatiga durant un microcicle estàndard. En aquest cas sembla ser que les variables DEC i HSS no van superar el volum del partit durant un microcicle estàndard. Addicionalment, els resultats més importants descoberts en les setmanes d’entrenament estàndard van consistir en una dinàmica en forma “d’U” invertida amb un pic de càrrega entre les sessions DP-3 i DP-2, un desacoblament entre l'RPE i el sRPE en les sessions DP-4 i, una alta correlació entre les variables de càrrega externa relacionades amb el volum i les variables de càrrega interna estudiades (especialment el sRPE).

## 12.3. Estudi 3

Els partits d'hoquei tenen escenaris de màxima exigència de 30 segons on les demandes són més altes que les demandes mitjanes descobertes en altres investigacions (Fernández et al., 2020), i que aquestes demandes màximes depenen de la posició, amb majors valors d'ACC per als jugadors interiors. A més d’això, els partits d'hoquei també inclouen múltiples exposicions a escenaris d'alta demanda que s'acosten a les exigències físiques màximes d'un partit. Per tant, es pot considerar la repetició d'escenaris com una mètrica més a controlar durant les sessions d'entrenament i comparar-la en funció dels resultats obtinguts en aquesta investigació.

## 12.4. Estudi 4

Sembla que la reducció de l'espai disminueix la DT que van recórrer els jugadors, però els permet assolir les mateixes ACC, DEC i temps passat per sobre del 90% de la FCmax que les trobades en partits a tota la pista. Les troballes d'aquest estudi permeten als entrenadors saber què passa a la pista quan es manipula la variable espacial durant partits. Reduir l'espai és una mesura que pot estimular referencialment la càrrega neuromuscular al reduir variables relacionades amb el volum i mantenir les variables relacionades amb l’aspecte neuromuscular de la càrrega.

# 13. Aplicacions pràctiques

Per facilitar la comprensió de les aplicacions pràctiques, aquestes han estat agrupades segons estudi.

## 13.1. Estudi 1

- L'aplicació practica més important té a veure amb la prescripció d'entrenament, i és que, interiors i exteriors afronten les mateixes demandes condicionals de forma mitjana durant una competició.
- La preparació i els entrenaments haurien de tenir en compte que els jugadors estudiats afronten demandes similars.

## 13.2. Estudi 2

- En primer lloc i de forma destacada permet entendre i observar com s'aplica una eina d'avaluació física que té en compte càrrega externa i interna. En aquest sentit, dona importància controlar la relació que estableixen els dos tipus de càrrega per poder ajustar entrenaments i sessions durant la setmana d'entrenament.
- En segon lloc, presenta referencies de volums i intensitats d'entrenament en un equip d'elit d'hoquei patins; cosa que entrenadors poden utilitzar com a punt de partida per ajustar i/o comparar les seves sessions.
- En tercer lloc, s'aconsella a preparadors físics utilitzar diferents variables de càrrega externa ja que no totes tenen relació amb al resposta mesurada en els jugadors.

## 13.3. Estudi 3

- L'aplicació de repetició d'escenaris, podria ajudar als entrenadors a programar diferents blocs d'entrenament de temps fixe (prescrits mitjançant la referència de la intensitat de l'escenari de màxima exigència individual) i determinar si el jugador està realitzant un volum per sota, igual o per sobre de les demandes del partit.
- Aquesta metodologia permet controlar les demandes de càrrega externa del cicle d'entrenament setmanal, mitjançant l'ús de la repetició d'escenaris de diferent intensitat (per exemple, baixa, moderada o elevada) per determinar per exemple quina sessió d'entrenament provoca una major repetició d'escenaris d'elevada intensitat.

## 13.4. Estudi 4

- Entrenadors i preparadors físics podrien obtenir beneficis d'utilitzar jocs reduïts en hoquei patins ja que aquests podria ser que reduïssin les demandes relacionades amb variables de volum com DT, mentre mantenen les demandes d'ACC i DEC al mateix nivell que en un partit normal.
- Sembla ser que la reducció d'espai a la meitat d'un partit estàndard, també permet mantenir unes demandes de càrrega interna similars a les del partit a pista completa; sempre i quan la tasca sigui realitzada amb la mateixa voluntat per part dels jugadors.

# 14. Futures línies d’investigació

Cal tenir en compte que, totes les conclusions extretes sobre els valors de càrrega externa i interna provenen d’estudis que tan sols han analitzat un equip, que ha jugat o entrenat a casa. Tenir precaució és necessari en el moment d’analitzar els resultats. Durant la redacció de la tesi hem intentat en tot moment ser prudents a l’hora d’interpretar els resultats, tenint més en compte la metodologia utilitzada que no els valors absoluts en sí mateixos.

Per tant, futures línies d’investigació principalment podrien consistir en analitzar dades de càrrega externa de més equips de hoquei sobre patins per aprofundir en el coneixement d'aquest esport i poder comprovar si els resultats obtinguts son transversals a tota una categoria o etapa (sèniors). Per exemple, competicions d’una única seu (torneigs d’estiu, copes del rei o competicions de seleccions) poden ser un bon començament ja que la mostra es concentra sempre en la mateixa pista i es poden analitzar equips diferents.

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# Capítol 5.

# Annex

# 16. Publicació article científic 1

Quantification of external load of elite rink hockey players in official matches

D. Fernández, F. Varo, G. Carmona, X. Reche.

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ORIGINAL ARTICLE
EXERCISE PHYSIOLOGY AND BIOMECHANICS

# Quantification of external load of elite rink hockey players in official matches

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ABSTRACT

BACKGROUND: The demands of elite rink hockey competition are unknown to coaches, although nowadays the explosion of tracking technology makes it possible to fill this research gap. The aims of this study were twofold: firstly, to describe the external load demands involved in a rink hockey match and secondly, to ascertain whether there were differences between exterior (EX) and interior or forward (IN) player positions.
METHODS: A retrospective observational study was conducted between 2017 and 2018 competitive season. Eight professional players (6 EX and 2 IN) participated voluntarily in the study during 9 official matches. Data logging was performed with a local positioning system and the variables studied were distance covered (DT), distance covered above 18 km/h (HSS), player load (PL), number of high-intensity accelerations (ACC) and number of high-intensity decelerations (DEC).
RESULTS: The average values per player were 4646±1135 m of DT for EX and 4919±1374 for IN, 897±252 m of HSS for EX and 981±313 for IN (mean ±SD); 173±69 and 167.5±57.5 ACC for EX and IN, respectively, and 164±56 and 152.5±42 DEC for EX and IN, respectively (median±IQR); and there were no significant differences (P>0.05), between positions.
CONCLUSIONS: The findings of this study allow us to ascertain the external load in matches and that EX and IN did not present different physical demands. With this information, coaches can adjust training loads more accurately.

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KEY WORDS: Hockey; Athletic performance; Athletes.

Rink hockey is a non-Olympic indoor team sport that is very popular in different countries such as Portugal, Italy, France, Argentina and Spain, among others. For example, in Catalonia it is the third team sport with most licenses after soccer and basketball.[1] It is played on a 40×20 m court between 2 teams of 5 players (four outfield players and a goalkeeper) and all the players use 4-wheel skates and a stick. As is common in other indoor team sports, there is an unlimited possibility of implementing changes between court and bench players. In 2009, the rules of play were changed to make it faster and more attractive to fans, thus leading to changes in the game models of teams and probably in competition requirements.

The bibliography that analyses the physical demands of the game[2, 3] dates mostly from the 1990s (only one study about competition load is after the change of rules in 2009), when rink hockey was an exhibition sport at the Barcelona '92 Olympic Games and a very minor sport compared to other team sports such as soccer,[4-6] basketball[7-10] or handball.[11, 12] The only research into load in competition after 2009 presents data from video analyses of 6 matches during the 2012 Spanish King's Cup.[3] Some noteworthy results included the fact that between 70% and 71% of player movements were made at low (0 to 2.4 steps/s) or medium intensity (2.5 to 4.9 steps/s), while the remaining 29% were high-intensity movements (>4.9 steps/s). Of these high-intensity movements, 82% lasted between 1 and 5 seconds. However, with all the information presented in the study, we continue to be unaware of variables such as player total distance, accelerations and decelerations. Therefore, there is a major information gap in terms of the external load demands involved in competition in modern rink hockey matches, which signifies an important disadvantage when presenting the content and magnitude of loads during training.

Almost all the research in indoor team sports competitions had been conducted using video analysis, although recently the boom of GPS devices, coupled with their reliability,[13] has made it easier to analyze both training and outdoor sports competition. Leveraging the improvements in local positioning such as ultra-wideband (UWB) technology[14, 15] allows us to obtain valid and reliable data from on-court events. Variables such as total distance, number and duration of accelerations and decelerations, meters of high-speed running, player load, high metabolic load distance, sprints and other variables are much more readily available now and this information could be very valuable for strength and conditioning coaches and technical staff. Thus, the aims of this study were firstly to quantify the external load demands related to a rink hockey match and subsequently to verify whether there were differences between player positions.

## Materials and methods

A retrospective observational study was conducted between 2017 and 2018 competitive season. The information on external load involved in a match was collected through a UWB positioning system (WIMU PRO™, Realtrack Systems, Almeria, Spain) during the official competition of a professional team of the highest Spanish male rink hockey category (Ok Liga) and which participated in the WSE Rink Hockey EuroLeague. A non-experimental, descriptive method was used to identify the demands of rink hockey matches and the differences between positions.

All the players of a professional rink hockey team (N.=8) (age: 29.6±5 years; weight: 78.1±4.6 kg; height: 178.8±3.1 cm) participated voluntarily in the study, while the goalkeepers were not included. In that season, 5 of the 8 players of the sample played for their respective national teams. There were two inclusion criteria: 1) that players finish the match without injury; and 2) that the players participated in the entire prematch training session, thus ensuring the inclusion of only players who were prepared for the match the day before it was played. Of these 8 players, there were 6 exteriors (EX) and 2 interiors or forwards (IN). All the information was collected during the 2017-2018 season, between September 2017 and February 2018. At the time of the study, the team was holding between 4 and 5 practice sessions a week and was playing 1 or 2 matches a week. The data analyzed stemmed from daily player monitoring, in which player activities are measured routinely during the season. Therefore, the approval of an ethics committee was not required,[16] although the study was conducted in accordance with the Declaration of Helsinki, and the players provided their informed consent before participating.

All matches recorded were official and began with a standard 30-minute warm-up for the players, and they were all played on the same court (always home) in the same environmental conditions. A total of 9 matches were included in the study and a total of 8 data files were saved for each match (if all the players met the aforementioned criteria), yielding a database that used 63 files. Whenever the players were not on the court they were excluded from the analysis. The mean duration and standard deviation of the time on court for EX was 40.3±15.7 minutes and 39.09±13.6 minutes for IN.

Data logging was performed with a local positioning system (WIMU PRO™, Realtrack Systems SL) and its corresponding software (SPRO™, Realtrack Systems SL, version 946). The devices were fitted to the upper back using tight harnesses. The WIMU PRO™ features four 3D accelerometers (full-scale out output ranges are ±16 g, ±16 g, ±32 g, ±400 g, 100 Hz sample frequency), three gyroscopes (8000°/s full-scale out output range, 100 Hz sample frequency) a 3D magnetometer (100 Hz sample frequency), a GPS (10 Hz sample frequency), a UWB (18 Hz sample frequency). The UWB system was installed on the court as follows: 4 antennae with UWB technology were placed 5 m from the perimeter line of the field. The WIMU PRO system presented better accuracy (bias: 0.5%7-5.85%), test-retest reliability (% technical error of measurement [% TEM]: 1.19) and inter-unit reliability (bias: 0.18) in determining distance than GPS technology (bias: 0.69-6.05%; % TEM: 1.47; bias: 0.25).[17] More recently, the WIMU PRO system presented a high intra-class correlation coefficient (ICC) value for the *x*-coordinate (0.65), a very high value for the *y*-coordinate (0.85) and a good % TEM: 2.[18]

The following variables were calculated in absolute terms and per minute to describe the demands and to analyze the differences between positions: 1) distance travelled in meters (DT; $m \cdot min^{-1}$); 2) distance covered above 18 km/h in meters (HSS>18 $km \cdot h^{-1}$; $m \cdot min^{-1}$); 3) player load, vector magnitude, expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each of the 3 planes divided by 100 in arbitrary units (PL; $AU \cdot min^{-1}$); 4) number of high-intensity accelerations (ACC; $>2 m \cdot s^{-2}$; N.$\cdot min^{-1}$); and 5) number of high-intensity decelerations (DEC; $>2 m \cdot s^{-2}$; N.$\cdot min^{-1}$). All these variables were selected because they were the most used ones in other descriptive studies of competition loads, and the thresholds used were the ones most emphasized in indoor sport research.[19-22]

### Statistical analysis

Data distribution was analyzed by the Shapiro-Wilk test and data homoscedasticity by the Levene test to check normal distribution. DT, HSS and PL presented normal distribution and equal variances. DT/min, HSS/min, ACC, ACC/min, DEC, DEC/min and PL/min did not present a normal distribution. The Student's *t*-test was used for normally distributed data. The Mann-Whitney U test was used for non-normally distributed data. The level of significance was defined as 0.05. The analysis for normally distributed data was presented as mean and standard deviation (SD) and for non-normally distributed data it was presented as the median and interquartile range (IQR).[23] Cohen's *d* was calculated for normally distributed data, and threshold values were 0-0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large and >2.0 very large.[24]

## Results

The variables studied are reported in Table I and Table II, expressed in means or medians depending on the statistical analysis applied. The tables also show the inference tests where none of the variables analyzed returned significant differences between positions. Data points in all variables and data distribution are presented in Figure 1.

TABLE I.—*Descriptive test and effect size statistics for parametric tests.*

| Outcome | G | N. | Mean | Std. Dev. | df | *t* | P | Cohen's *d* |
|---|---|---|---|---|---|---|---|---|
| DT (m) | EX | 37 | 4645.66 | 1135.20 | 47.20 | -0.833 | 0.409 | 0.19 |
| | IN | 26 | 4918.84 | 1373.82 | | | | |
| HSS (m) | EX | 37 | 896.58 | 251.76 | 46.29 | -1.139 | 0.260 | 0.26 |
| | IN | 26 | 980.88 | 312.74 | | | | |
| PL (AU) | EX | 37 | 26.47 | 6.37 | 54.73 | 0.517 | 0.607 | 0.12 |
| | IN | 26 | 25.63 | 6.23 | | | | |

DT: Distance traveled; HSR: high-speed skating; PL: player load.

TABLE II.—*Descriptive and test statistics for non-parametric tests.*

| Outcome | G | N. | Median | IQR | U | z | P |
|---|---|---|---|---|---|---|---|
| DT/min (m) | EX | 37 | 129.72 | 21.15 | 446 | -0.489 | 0.625 |
| | IN | 26 | 132.14 | 23.65 | | | |
| HSS/min (m) | EX | 37 | 24.8 | 5.48 | 410 | -0.991 | 0.322 |
| | IN | 26 | 26.79 | 6.09 | | | |
| ACC (N.) | EX | 37 | 173 | 69 | 466 | -0.209 | 0.834 |
| | IN | 26 | 167 | 57.5 | | | |
| ACC/min (N.) | EX | 37 | 4.84 | 1.42 | 438 | -0.600 | 0.548 |
| | IN | 26 | 4.75 | 1.16 | | | |
| DEC (N.) | EX | 37 | 164 | 56 | 407.5 | -1.026 | 0.305 |
| | IN | 26 | 152.5 | 42 | | | |
| DEC/min (N.) | EX | 37 | 4.57 | 1.51 | 386.5 | -1.319 | 0.187 |
| | IN | 26 | 4.27 | 0.98 | | | |
| PL/min (AU) | EX | 37 | 0.72 | 0.17 | 371.5 | -1.530 | 0.126 |
| | IN | 26 | 0.70 | 0.08 | | | |

DT: Distance traveled; HSS: high-speed skating; ACC: high-intensity accelerations; DEC: high-intensity decelerations; PL: player load.

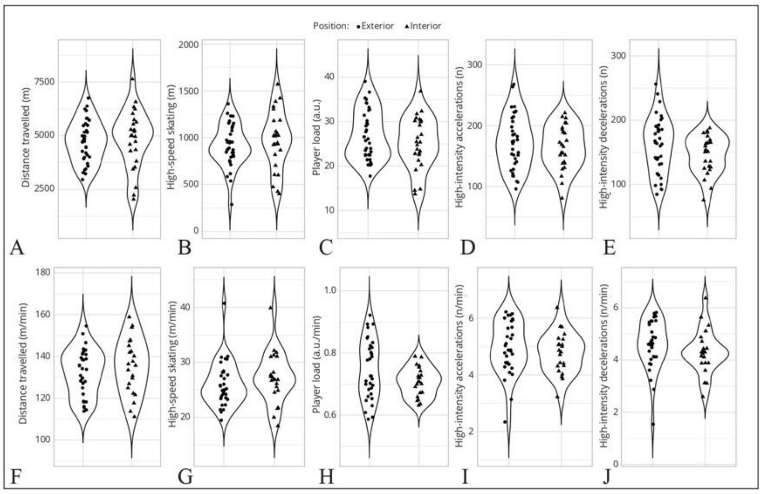


Figure 1.—A-J) Violin plot and data distribution for all variables.

## Discussion

This is the first study to quantify the external load of elite rink hockey players in official competition and to examine whether there were differences between positions in the same scenario. The main findings of the investigation were that for the first time it was possible to describe the average external load demands of rink hockey game of an elite team and secondly that there were no differences between EX and IN in all the variables studied.

With regard to the first objective, due to the non-existence of publications that describe rink hockey external load competition demands through positioning technology, we were only able to compare our results with other research that used video recordings in the same sport or published papers that used local positioning systems in other indoor sports, regardless of player position. Furthermore, the small sample size, due to the very high level of the players analyzed, means that caution should be exercised when universalizing these results to other rink hockey teams, especially if they do not have the elite status.

Regarding external load competition demands, the DT data from this study place rink hockey clearly behind outdoor sports such as soccer[25, 26] and rugby.[27] This is an expected outcome since, like other indoor sports, rink hockey has a smaller court area and a shorter match duration.[28] Moreover, the use of absolute distance values such as DT masks an important feature of indoor sports, namely continuous substitution policies. Therefore, the use of mean relative distance values (DT/min) rather than mean absolute values (DT) has been proposed as an appropriate tool for the comparison of external load volume metrics.[9] Then, the DT/min of the rink hockey team analyzed is higher than other indoor sports analyzed in the scientific literature such as futsal,[19, 29] handball[20] or basketball.[30] Interestingly, this could be explained by the fact that the use of skates in rink hockey makes it easy to move around the court and more difficult to remain motionless in one place; and probably the use of fences around the court is a fundamental difference between the sports compared, meaning that there are fewer in-game interruptions in rink hockey.

Another important point in external load quantification is to analyze the mechanical load of a rink hockey match. Compared to other indoor and outdoor team sports, the main difference lies in the way that the players move about the court. Some research has been done in basketball in this field, and in two works[21, 22] the authors found mean values of PL/min smaller than the values found in our research and in soccer we found one piece of research[30] analyzing four official matches of under-18 players with mean values smaller than those of our data as well. It may be that the use of skates to move in comparison with running had less impact on the vertical axis, thus accumulating less PL/min. As we mentioned in the introduction, the major gap in the literature with regard to rink hockey means that there is no evidence that the biomechanics of skating differ from running in terms of external load, although the results seem to suggest that the team analyzed had more DT than other indoor sports in relative mean values but with lower PL values in relative mean values as well. Some research[31] suggests that the ratio between velocity load (DT/min) and mechanical load (PL/min) could be a metric of the amount of force or ground impulses required per unit of displacement, used to asses neuromuscular or running (in our case skating) efficiency; with our results, this ratio may be higher than other running sports (more distance per force load), with the aforementioned relationship of more DT/min and lower PL/min values.

It is interesting to note that there is a trend in the difference between the number of ACC and DEC in all players in absolute and relative results. In rink hockey, the use of skates may mean that stopping a movement is more demanding than starting one. When players complete an action, their movement will normally continue due to the wheels, hence a DEC action probably requires a major amount of eccentric strength and energy expenditure. These results tally with other basketball research[22] conducted also with WIMU sensors in which, in 3 different court conditions, all the player positions studied had more ACC than DEC per minute in three different 5 *vs.* 5 game formats. On the other hand, three soccer research works[32-34] show that the mean values per minute of ACC are similar to the mean values per minute of DEC. In any event, the deceleration action is important because it is part of a change-of-direction skill, which is key to superior performance.[35]

In relation to the second aim of the study, the findings tallied with previous rink hockey-related research. We found no differences between positions in any of the variables analyzed, as neither have the authors of previous research works.[3] These results may be accounted for by the high exchange of positions between players during the match, in which the great dynamics of the sport leads all players to occupy different positions. On the other hand, on comparing our findings to those of other studies that analyze players' external load by positions in other sports with local or global positioning systems, we observed differences in distances covered at different speeds, accelerations and decelerations by positions. As in the case of basketball,[36] where power forwards presented the lowest total external load (similar variable to PL) compared to other positions; or in another basketball study, which suggested that basketball centers had lower acceleration and deceleration demands during a match, whereas there were no differences between guards and forwards; or finally in handball,[37] where backs were more prone to engaging in high-intensity events (accelerations, changes of direction and decelerations) than the other positions. It is interesting to note that despite the small sample size, this finding could make rink hockey special, as in the literature reviewed, and to the best of our knowledge, it could be the only indoor team sport where there are no differences between positions in terms of external loading.

### Limitations of the study

The previous statement, and others in the discussion, should be approached with caution, because only one team, playing at home, was analyzed, meaning that other spurious variables not analyzed, such as playing away, winning or losing, were not taken into account and could interfere in the results.

## Conclusions

In conclusion, this work describes, for the first time, competitive rink hockey physical demands, in terms of external load, in an elite team context. In this regard, it is important to stress that there are no differences in the external load variables measured between EX and IN positions in rink hockey matches. We would encourage other sport scientists to analyze and report the external load data from other rink hockey teams to further knowledge of this sport.

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*Conflicts of interest.*—The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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# 17. Publicació article científic 2

Integrating External and Internal Load for Monitoring Fitness and Fatigue Status in Standard Microcycles in Elite Rink Hockey

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# Integrating External and Internal Load for Monitoring Fitness and Fatigue Status in Standard Microcycles in Elite Rink Hockey

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Fernández D, Moya D, Cadefau JA and Carmona G (2021) Integrating External and Internal Load for Monitoring Fitness and Fatigue Status in Standard Microcycles in Elite Rink Hockey. Front. Physiol. 12:698463. doi: 10.3389/fphys.2021.698463

The aims of this study were 3-fold: firstly, to present an integrative approach to external and internal load dynamics for monitoring fitness and fatigue status of specific in-court rink hockey training sessions in a standard microcycle; secondly, to assess the differences between training sessions and matches; the third and final aim was to assess the association between external and internal load metrics. The external load, using a local positioning system, and internal load, using the declared rate of perceived exertion, were measured during 23 in-season microcycles for nine top-level players. Training load data were analysed with regard to the number of days before or after a match [match day (MD) minus or plus]. In relation to the first aim, internal and external load metrics merged into a single integrated system using pooled data *z*-scores provided an invisible monitoring tool that places the players in the fitness-fatigue continuum throughout the different microcycle sessions. In this regard, MD-4 and MD-1 sessions tend to place, with a low dispersion, the players in a "low external and internal load" zone. On the contrary, in MD-3 and MD-2 sessions, as well as in MD, in which higher loads were recorded, most of the players were within a "high external and internal load" zone with a tendency towards dispersion towards the fitness or fatigue zones. Finally, and with regard to the second and third aims, an inverted "*U*-shape" load dynamic related to the specific goals of each training session was the main finding in terms of comparison between MD; a load peak between MD-3 and MD-2 sessions and a significant decrease in all the load variables in MD-1 sessions were found; and high-to-low correlations were found between external and internal load metrics. This study presents an integrative approach to the external and internal load of players for monitoring fitness and fatigue status during a standard microcycle in rink hockey that might provide team sport staff members with a deeper understanding of load distribution in the microcycle in relation to the match.

**Keywords: team sport, load control, ultrawide-band, LPS, GPS**

## INTRODUCTION

Workload in the context of sports training has been defined as the input variable which, assuming a certain level of stress, is manipulated to obtain a desired response (Impellizzeri et al., 2019). While training load is totally manipulable, competition load, due to its intrinsic characteristics such as results, place in the league table, stage of the season or type of league, is much less so and is limited to the possibility of regulating player exposure to it (minutes of play). Load can be described as internal or external (Impellizzeri et al., 2019). External load (EL) is the work completed by the player independently of his or her internal characteristics; for example, it is described in terms of distance, accelerations, decelerations, or sprints, among others (Varley and Aughey, 2013). The resulting physiological, psychological, and biomechanical stress imposed, described as internal load (IL), drives player adaptation response (Vanrenterghem et al., 2017). The outcome of any training intervention is therefore the consequence of both EL and IL, hence reliable monitoring tools are crucial to the optimisation of athletic performance (Impellizzeri et al., 2019) and to a better understanding of the factors affecting sport performance and recovery, since the uncoupling or divergence of EL and IL may differentiate between a non—fatigued and a fatigued athlete (Thorpe et al., 2017). Current models of the fitness—fatigue relationship use the association between EL and IL (Delaney et al., 2018), considering "fatigue" as the ability to complete a task or training session with an altered IL response which recent had been achievable with a lower IL response and "fitness state" as the opposite, the ability to accumulate a given EL with a lower IL response.

Thanks to tracking technology, athletes, coaches and sport scientists, can easily compile EL parameters to help practitioners and coaches to plan, evaluate, structure and optimise their training methodology (Borresen and Lambert, 2009). The use of electronic performance and tracking systems has helped to compare competition demands to training session drills and consequently modulate the intensity and volume of these training sessions according to the match day (Buchheit et al., 2014). Moreover, the use of subjective scales to record the declared exertion also makes it possible to obtain information about IL (Foster et al., 2001).

The organisation of training loads can be divided into macrocycles, mesocycles and microcycles (Naclerio et al., 2013). These divisions make it possible to organise the load from very large time cycles (for example macrocycles that encompass two seasons), through mesocycles that group several weeks or months of training, up to weekly microcycles. The most recent research in team sports is beginning to identify the microcycle as the most important planning unit in this type of sport in this specific case, understanding the microcycle not as the training week, but as the time that passes between one game and another (Tarragó et al., 2019). Indeed, many studies have provided comprehensive information about EL of outdoor elite team sports during matches, and some studies have furnished the same information about indoor elite team sports (Vázquez-Guerrero et al., 2019; Gómez-Carmona et al., 2020; Ribeiro et al., 2020), including high-intensity actions and metabolic variables. Research relating elite teams' in-season microcycles in outdoor sports is on the increase (Akenhead et al., 2016; Martín-García et al., 2018; Oliveira et al., 2019) but is virtually non-existent in indoor sports (Illa et al., 2020).

Being an indoor sport, rink hockey is a team sport involving skates and a stick and is characterised by high-intensity actions such as accelerations, decelerations, sprints, and changes of direction (Fernández et al., 2020b). Rink hockey is played in a 40 × 20 m court like futsal or handball, but with fences, a structural difference that means that there are fewer interruptions than in these other sports. It is played by two teams of four players and a goalkeeper, and official matches have two halves of 25 min; the number of players and the court size make rink hockey more similar to futsal than to basketball and handball in terms of density of players. Finally, the use of roller skates makes the movement of the players on the court much easier; they are able to cover large distances, sometimes without effort. Finally, decelerations and accelerations are the key actions in this sport (Fernández et al., 2020b). While the use of technology in certain team sports modalities has increased in the last decade, research into conditional demands is scant. Some research has addressed official matches (Merino Tantiña et al., 2014; Fernández et al., 2020b) and the most demanding passages in certain drills (Fernández et al., 2020a), although microcycle training load dynamics has never been described.

Accordingly, this research pursued three aims: (i) to present an integrative approach to EL and IL dynamics for monitoring the fitness and fatigue status in the specific in-court training sessions of an elite rink hockey team for a standard one-match-per-week microcycle; (ii) to evaluate the differences in EL and IL metrics between training sessions and match; and (iii) to assess the association between EL and IL metrics.

## MATERIALS AND METHODS

### Participants

Elite professional rink hockey players ($n$ = 9, age: 29.8 ± 5.77 years, weight: 79.5 ± 5.50 kg, height 180.4 ± 4.03 cm, all measurements mean ± standard deviation) participated voluntarily in the study, whereas the goalkeepers were not included. In the two seasons analysed, the team won the Spanish First Division championship and seven of the nine players of the sample played for their respective national teams in official tournaments. The data analysed came from daily player monitoring, in which player activities were routinely measured throughout the season. The experimental procedures used in this study were approved by the local Ethics and Scientific Committee and all the players signed an informed consent form before participating.

**Abbreviations:** EL, external load; IL, internal load; declared RPE, declared rate of perceived exertion; s-RPE, session rate of perceived exertion; MD, match day; MD-x, match day [MD] minus X days; DT, distance travelled; HSS, high-speed skating; ACC, high-intensity accelerations; DEC, high-intensity decelerations; ES, effect size.

## Methodology

A retrospective observational study was carried out during the 2018–2019 and 2019–2020 competitive seasons (in the latter only until March 2020 due to COVID-19). A non-experimental descriptive method was used to identify the demands of rink hockey microcycle training sessions and matches and to evaluate the differences between days. A correlation analysis was conducted to describe the relationship between EL and IL metrics. The training load data were analysed with regard to the number of days before the match [match day (MD) minus X days] (Akenhead et al., 2016).

As it has been noted in the introduction, the microcycle it is the most important programming unit in team sports training. Tarragó et al. (2019) defined a microcycle as the time that elapses between competitive matches, and stated that its goal is to achieve the best training possible and consider the loads of the competitive matches within the dynamic of the weekly load, considering them the most important factor that affects the other sessions. The number of competition matches per week, days between matches and the physical condition of the players and the team, among other conditioning factors, affected the structure of each microcycle throughout the season. Due to all these variations, the inclusion criteria for the standard microcycles analysed were: (1) microcycles with only one match per week, (2) microcycles with four training sessions before the match, (3) microcycles with 1 day of rest after the previous match, and (4) microcycles in which the matches were official. Once the microcycles had been chosen, the inclusion criteria for the players analysed in each session were: (1) the player had to complete the entire session and (2) the player had to be available for the match. With these criteria, a total of 23 in-season microcycles were chosen out of a total of 75, with 20 MD-4 sessions, 23 MD-3 sessions, 20 MD-2 sessions, 11 MD-1 sessions, and 8 MD official matches. The mean durations (and standard deviations) of the sessions were, 62.3 $\pm$ 4.26 min for the MD-4, 85.4 $\pm$ 4.91 min for MD-3, 76.5 $\pm$ 8.46 min for MD-2, 56.1 $\pm$ 3.24 min for MD-1, and 90.4 $\pm$ 4.99 min for MD. The missing session data (for example, only 11 MD-1 sessions of the 23 microcycles were analysed) were due to factors beyond the researcher's control (e.g., technical issues with equipment) or because training sessions had been arranged on other training courts and facilities for logistical and schedule reasons. The matches and specific in-court training sessions analysed were always played on the same court (always at home), ensuring the same environmental conditions.

The training sessions of the microcycles analysed in this research were always comprised of an integrated content (i.e., tactical, technical, and physical factors were amalgamated) and in line with the structured training and structured microcycle methodology (Tarragó et al., 2019). The main goals and drills used in each training session are provided in **Figure 1**.

## Procedures

Data logging to evaluate EL was performed with a local positioning system (WIMU PRO™, Realtrack Systems SL) and its corresponding software (SPRO™, Realtrack Systems SL, version 962). The devices were fitted to the upper back using tight harnesses. The WIMU PRO™ features four 3D accelerometers (full-scale out output ranges are $\pm$ 16 g, $\pm$ 16 g, $\pm$ 32 g, $\pm$ 400 g, 100 Hz sample frequency), three gyroscopes (8,000°/s full-scale out output range, 100 Hz sample frequency), a 3D magnetometer (100 Hz sample frequency), a GPS (10 Hz sample frequency), and ultra-wideband (18 Hz sample frequency). The ultra-wideband system was installed on the court as follows: six antennae with ultra-wideband technology were placed 5 m away from the perimeter line of the field. The WIMU PRO system presented a high intra-class correlation coefficient value for the x-coordinate (0.65), a very high value for the y-coordinate (0.85) and a good % technical error of measurement: two (Bastida Castillo et al., 2019).

The following variables were calculated in absolute terms to describe EL: distance travelled in metres (DT; m); high-speed skating, distance covered above 18 km/h in metres (HSS >18 $km \cdot h^{-1}$; m); player load, vector magnitude, expressed as the square root of the sum of the squared instantaneous rates of change in acceleration in each one of the three planes divided by 100 in arbitrary units (PL; AU); number of high-intensity accelerations (ACC; >2 $m \cdot s^{-2}$; n) and number of high-intensity decelerations (DEC; >2 $m \cdot s^{-2}$; n). All of these variables were selected because they were the most commonly used ones in other competition load descriptive studies and the thresholds used were the ones emphasised most in indoor sport research and previously described in rink hockey (Fernández et al., 2020b).

Each player's declared rate of perceived exertion (declared RPE) was collected ~30 min after each specific in-court training session or match using the 0–10 point Borg's rate of perceived exertion scale modified by Foster et al. (2001), with its respective verbal anchors, in order to collect subjective IL estimations. All the players were familiar with the use of the scale. A smartphone app was used to avoid bias and maintain subjectivity in player response. Subsequently, specific in-court session declared RPE (s-RPE) was calculated by multiplying the specific session (or game) duration in minutes by the individual declared RPE scores for the training (or game) and was presented in arbitrary units (a.u.) (Foster et al., 2001). s-RPE has been proposed as a cost-effective alternative to heart rate-based methods as a global measure of training intensity that may more accurately quantify IL in intermittent sports (Impellizzeri et al., 2004; Paulson et al., 2015). Both declared RPE (0–10 point scale) and s-RPE (a.u.) results were used for further analyses.

## Statistical Analysis

All statistical analyses were conducted with RStudio version 1.3.1093 (RStudio, Inc.) and "readxls," "tidyr," "dplyr," "ggridges," "plyr," "ggplot2," "scales," "viridis," "pipeR," "effsize," "bootES," "officer," and "rvg" packages. Descriptive results were reported as mean $\pm$ standard deviation and a $z$-score analysis was conducted with the pooled s-RPE data and the mean of all $z$-score EL variable pooled data. The data failed all the tests for homogeneity of variance (Levene's test) and most of the variables and MD for normality (Shapiro–Wilk test). A bootstrap confidence interval (CI) approach was used to perform the hypothesis test to assess the differences between MDs because the assumptions of this method were aligned with our data (Tian, 2010). A residual

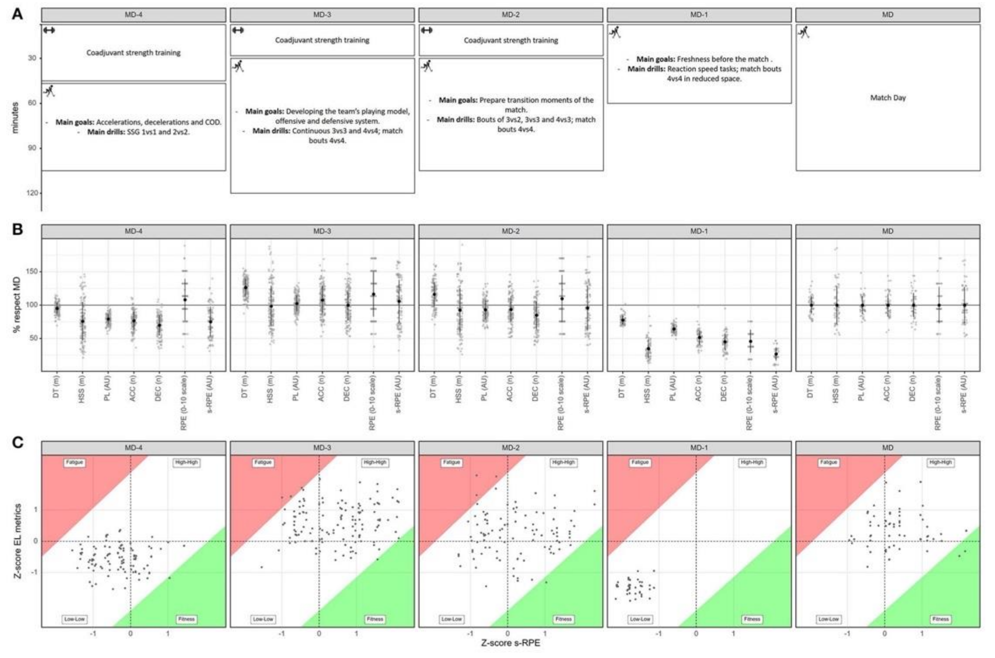


**FIGURE 1 |** Integrative approach overview of a standard microcycle. **(A)** Main goals, characteristics, and training drills used in each session. **(B)** Mean, standard deviation and data distribution of each session expressed as a percentage of match values. **(C)** Distribution of the mean of the EL metrics *z*-scores (EL metrics *z*-scores) and the IL s-RPE *z*-scores of pooled data from all sessions. DT, Distance travelled; HSS, High-speed skating; PL, Player Load; ACC, High-intensity accelerations; DEC, High-intensity decelerations; RPE, Declared rate of perceived exertion; s-RPE, Rate of perceived exertion × total duration of session; MD, Match Day.

resampling model with 10,000 bootstrap samples and 95% bias-corrected and accelerated method (BCa 95% CI) was used to calculate the CI of *F*-values of repeated-measures ANOVA for each variable and established that the null hypothesis, that there were no differences, was true if one fell within the CI limits (Plonsky, 2015). The same bootstrap CI approach with a simple resampling model was used to evaluate the *post hoc* pairwise comparisons. The mean difference and effect size value was computed and presented as pairwise change. Thresholds for effect size (ES) statistics were (ES $< 0.20$), trivial; ($0.20 <$ ES $< 0.59$), small; ($0.60 <$ ES $< 1.19$), moderate; ($1.20 <$ ES $< 1.99$), large; and (ES $> 2.0$), very large (Hopkins et al., 2009). Finally, a bootstrapped Pearson correlation test was conducted to quantify the correlation between s-RPE and all the EL variables. The magnitude of correlation coefficients, according to Hopkins (2016), was considered trivial ($r < 0.1$), small ($0.1 < r < 0.3$), moderate ($0.3 < r < 0.5$), large ($0.5 < r < 0.7$), very large ($0.7 < r < 0.9$), almost perfect ($r > 0.9$), or perfect ($r = 1$). All the reported *P*-values were the likelihoods of the absolute effect sizes being observed if the null hypothesis of zero difference was true (Plonsky, 2015).

## RESULTS

The EL and IL descriptive results are represented in **Figure 1** and in **Table 1**. The MD-3 training sessions were the ones with the highest values (except the HSS variable, where the MD is the session with the highest values). In addition, **Figure 1** presents an overview of all the microcycle mean values, with descriptive results relative to match values and *z*-score values of EL (presented as the mean of all *z*-score EL variables) and s-RPE metric for each training session; MD-1 sessions were the ones with the lowest relative load values and the lowest EL and IL demands measured in *z*-score values.

The ANOVA results of all the variables studied are presented in **Table 2**, there being significant differences in all the metrics analysed. Finally, the change of each variable in each pairwise comparison between the different MD is represented in **Table 3** in the form of absolute changes (in the respective units) and effect size changes (in Cohen D units). MD-3 were the training sessions most similar to the match, except in DT, ACC, and declared RPE, in which it surpassed the match values; on the other hand, MD-1 were the training sessions with the most significantly lowest

**TABLE 1** | Descriptive statistics (mean ± standard deviation) for all variables each match day.

| Variables | MD-4 | MD-3 | MD-2 | MD-1 | MD |
|---|---|---|---|---|---|
| DT (m) | 5,289 ± 466 | 7,035 ± 754 | 6,463 ± 1,014 | 4,324 ± 379 | 5,568 ± 750 |
| HSS (m) | 560 ± 212 | 727 ± 225 | 683 ± 245 | 256 ± 103 | 739 ± 209 |
| PL (a.u.) | 26.9 ± 2.70 | 34.8 ± 4.15 | 31.6 ± 4.85 | 21.8 ± 2.10 | 34.0 ± 4.54 |
| ACC (*n*) | 122 ± 22.0 | 172 ± 33.7 | 149 ± 31.9 | 82.4 ± 17.6 | 160 ± 26.6 |
| DEC (*n*) | 99.9 ± 21.7 | 143 ± 31.9 | 121 ± 30.1 | 64.4 ± 18.3 | 143 ± 25.8 |
| Declared RPE (0–10 scale) | 5.71 ± 1.64 | 6.16 ± 1.78 | 5.80 ± 1.87 | 2.43 ± 0.90 | 5.29 ± 1.45 |
| s-RPE (a.u.) | 356 ± 107 | 501 ± 153 | 454 ± 158 | 126 ± 47.3 | 474 ± 129 |

*DT, Distance travelled; HSS, High-speed skating; PL, Player Load; ACC, High-intensity accelerations; DEC, High-intensity decelerations; RPE, Rate of perceived exertion; s-RPE, Rate of perceived exertion × total duration of session; MD, Match day.*

**TABLE 2** | Bootstrap ANOVA results for each variable.

| Variable | *F* | Bootstrap* | | | |
|---|---|---|---|---|---|
| | | Bias | Std. Error | BCa 95%CI Lower | BCa 95%CI Upper |
| DT (m) | 242 | 24.1 | 25.7 | 185 | 266.3 |
| HSS (m) | 92.4 | 9.52 | 12.0 | 65.1 | 106.0 |
| PL (a.u.) | 229 | 22.9 | 23.7 | 172 | 251 |
| ACC (*n*) | 224 | 22.0 | 23.0 | 167 | 245 |
| DEC (*n*) | 261 | 25.3 | 26.6 | 199 | 286 |
| Declared RPE (0–10 scale) | 70.5 | 10.2 | 10.9 | 45.4 | 81.1 |
| s-RPE (a.u.) | 111 | 15.8 | 15.1 | 80.5 | 124 |

*DT, Distance travelled; HSS, High-speed skating; PL, Player Load; ACC, High-intensity accelerations; DEC, High intensity-decelerations; RPE, Rate of perceived exertion; s-RPE, Rate of perceived exertion × total duration of session. The null hypothesis was rejected if 1 did not fall within BCa 95% CI limits. *Bootstrap results are based on 10,000 bootstrap samples.*

values in all the metrics studied compared to the other training sessions and the match.

The correlation data analysed between EL and IL (s-RPE) are shown in **Figure 2**. There was a large positive correlation with DT and PL variables, moderate with ACC and DEC variables and a small positive correlation with the HSS metric.

## DISCUSSION

The aims of this research were (i) to present an integrative approach to the EL and IL dynamics for monitoring the fitness and fatigue status of specific in-court training sessions of an elite rink hockey team for a standard microcycle, (ii) to evaluate the EL and IL differences between all the training sessions and matches, and (iii) to assess the correlation between EL and IL metrics. To the best of our knowledge, this is the first study to carefully describe the EL and IL dynamics of a microcycle of an elite rink hockey team. In this regard, our results revealed an inverted "*U*-shape" load dynamics in which MD-3 and MD-2 were the two training sessions with the greatest EL and IL of the microcycle in comparison with the other sessions and slightly above the match. Finally, and with regard to the association between EL and IL metrics, large and moderate correlations were found between volume-related variables and s-RPE and low correlations were found between high-intensity-related variables and s-RPE.

### Integrative Approach to Training Loads

One of the novelties presented by this study was the determination of the EL and IL dynamics during a standard microcycle comprised of two consecutive seasons. **Figure 1** provides a visual overview of a standard microcycle content (**Figure 1A**), training load dynamics (**Figure 1B**) and an integrative approach of EL and IL for player fitness and fatigue status monitoring based on the proposals by Gabbett et al. (2017) and Delaney et al. (2018) (**Figure 1C**).

With regard to load dynamics, our monitoring approach showed that both EL and IL represented an inverted "*U*-shape" curve throughout a standard microcycle (**Figure 1B**). Regarding EL, the inverted "*U*-shape" presented is like other EL dynamics described elsewhere in other team sport microcycles, such as soccer (Akenhead et al., 2016; Los Arcos et al., 2017; Owen et al., 2017; Martín-García et al., 2018). Other research in soccer showed a decrease from MD-4 sessions to MD (Stevens et al., 2017), and finally, Malone et al. (2014), also in soccer, found no differences between MD-4, MD-3, and MD-2 training sessions. This inverted "*U*-shape" curve seems to correspond to a tapering strategy (Martín-García et al., 2018) in which EL decreases as match day approaches. Interestingly, the most notable characteristic of IL dynamics in our study was the difference between the inverted "*U*-shape" of the s-RPE metric (following the same pattern as EL metrics) versus the flat shape described by the declared RPE (0–10 point scale) variable throughout MD-4, MD-3, and MD-2 training sessions (**Figure 1B**). This declared RPE (0–10 point scale) dynamic might be explained by the fact that this variable is a nominal score given by the player that mainly describes mean training intensity (Haddad et al., 2017), while the s-RPE metric takes not only the intensity but also the duration of the session into consideration (Foster et al., 2001). Excepting MD-1, MD-4 is the shortest of the other three types of training days; this is why, when multiplying the declared RPE by time, the s-RPE was lowest in MD-4 training sessions.

**TABLE 3 |** 95% Confidence interval of absolute change and effect size change between match days.

| Pairwise | | DT (m) | | HSS (m) | | PL (a.u.) | | ACC (*n*) | | DEC (*n*) | | Declared RPE (0–10 scale) | | s-RPE (a.u.) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 95CI lwr. | 95CI upr. | 95CI lwr. | 95CI upr. | 95CI lwr. | 95CI upr. | 95CI lwr. | 95CI upr. | 95CI lwr. | 95CI upr. | 95CI lwr. | 95CI upr. | 95CI lwr. | 95CI upr. |
| MD - MD-4 | Abs. Δ | **74.6** | **488** | **118** | **246** | **5.93** | **8.47** | **29.9** | **45.5** | **35.9** | **50.9** | –0.91 | 0.09 | **78.9** | **158** |
| | ES Δ | **0.12** | **0.85** | **0.54** | **1.14** | **1.73** | **2.49** | **1.23** | **1.93** | **1.53** | **2.21** | –0.58 | 0.05 | **0.68** | **1.35** |
| MD - MD-3 | Abs. Δ | **–1,687** | **–1,241** | –48.4 | 77.5 | –2.11 | 0.60 | **–20.5** | **–3.38** | –8.01 | 8.73 | **–1.33** | **–0.36** | –68.0 | 17.1 |
| | ES Δ | **–2.28** | **–1.57** | –0.23 | 0.35 | –0.50 | 0.13 | **–0.65** | **–0.10** | –0.27 | 0.27 | **–0.82** | **–0.21** | –0.48 | 0.11 |
| MD - MD-2 | Abs. Δ | **–1,141** | **–634** | –6.35 | 127 | **0.97** | **3.80** | **1.91** | **19.1** | **13.4** | **30.2** | –1.04 | 0.03 | –25.5 | 65.6 |
| | ES Δ | **–1.23** | **–0.66** | –0.04 | 0.52 | **0.19** | **0.79** | **0.06** | **0.62** | **0.45** | **1.03** | –0.60 | 0.01 | –0.18 | 0.44 |
| MD - MD-1 | Abs. Δ | **1,035** | **1,457** | **429** | **546** | **10.9** | **13.5** | **69.7** | **85.5** | **70.9** | **86.6** | **2.42** | **3.35** | **313** | **386** |
| | ES Δ | **1.68** | **2.66** | **2.52** | **3.53** | **2.89** | **4.14** | **2.79** | **4.11** | **2.89** | **4.10** | **1.86** | **2.68** | **2.81** | **3.86** |
| MD-4 - MD-3 | Abs. Δ | **–1,878** | **–1,606** | **–217** | **–117** | **–8.71** | **–7.14** | **–56.2** | **–43.5** | **–49.4** | **–37.1** | –0.89 | 0.01 | **–179** | **–111** |
| | ES Δ | **–3.05** | **–2.41** | **–0.98** | **–0.53** | **–2.48** | **–1.92** | **–1.96** | **–1.46** | **–1.79** | **–1.31** | –0.52 | 0.00 | **–1.36** | **–0.81** |
| MD-4 - MD-2 | Abs. Δ | **–1,356** | **–989** | **–175** | **–68.0** | **–5.72** | **–3.92** | **–33.5** | **–20.6** | **–27.7** | **–15.4** | –0.58 | 0.39 | **–136** | **–61.8** |
| | ES Δ | **–1.75** | **–1.21** | **–0.76** | **–0.30** | **–1.45** | **–0.98** | **–1.22** | **–0.74** | **–1.06** | **–0.57** | –0.33 | 0.24 | **–1.01** | **–0.46** |
| MD-4 - MD-1 | Abs. Δ | **838** | **1,071** | **262** | **346** | **4.31** | **5.68** | **34.5** | **45.3** | **29.9** | **40.9** | **2.86** | **3.71** | **205** | **256** |
| | ES Δ | **1.79** | **2.57** | **1.41** | **1.92** | **1.64** | **2.29** | **1.54** | **2.29** | **1.36** | **2.06** | **1.86** | **2.60** | **2.10** | **2.81** |
| MD-3 - MD-2 | Abs. Δ | **362** | **769** | –9.03 | 97.7 | **2.12** | **4.12** | **15.3** | **29.8** | **14.6** | **28.3** | –0.13 | 0.83 | **4.78** | **85.9** |
| | ES Δ | **0.41** | **0.88** | –0.04 | 0.42 | **0.45** | **0.94** | **0.45** | **0.91** | **0.46** | **0.92** | –0.07 | 0.46 | **0.03** | **0.57** |
| MD-3 - MD-1 | Abs. Δ | **2,556** | **2,843** | **430** | **512** | **12.1** | **13.7** | **82.9** | **96.0** | **72.1** | **84.9** | **3.30** | **4.14** | **343** | **404** |
| | ES Δ | **3.61** | **4.54** | **2.13** | **2.66** | **3.14** | **3.91** | **2.64** | **3.37** | **2.42** | **3.10** | **1.97** | **2.63** | **2.45** | **3.10** |
| MD-2 - MD-1 | Abs. Δ | **1,954** | **2,328** | **380** | **474** | **8.89** | **10.7** | **60.4** | **73.6** | **50.6** | **63.5** | **2.91** | **3.84** | **294** | **363** |
| | ES Δ | **2.17** | **2.85** | **1.78** | **2.32** | **2.08** | **2.66** | **2.05** | **2.74** | **1.81** | **2.45** | **1.73** | **2.34** | **2.13** | **2.72** |

*The confidence intervals are based on the BCa method and 10,000 bootstrap samples. Significant differences ($p < 0.05$) are displayed in bold.*
*DT, Distance travelled; HSS, High-speed skating; PL, Player Load; ACC, High-intensity accelerations; DEC, High-intensity decelerations; RPE, Rate of perceived exertion; s-RPE, Rate of perceived exertion × total duration of session; MD, Match Day; CI, Confidence interval; ES, Effect Size; lwr, lower; upr, upper.*

Finally, **Figure 1C** presents the IL and EL metrics merged into an integrated system using pooled data $z$-scores; this type of load monitoring approach, based on Gabbett et al. (2017) and Delaney et al. (2018), provides a monitoring tool that places the players in the fitness-fatigue continuum throughout the different microcycle sessions without using tests. This approach uses the relationship between IL and EL metrics in attempt to detect uncoupling between metrics, in other words, attempt to detect when a given EL had a lower (fitness) or greater (fatigue) IL response. Moreover, the use of pooled data helps the observer to see the type of training session and its dispersion with respect to the others, and the quadrant in which it is located intra and inter sessions. In this regard, **Figure 1C** shows that MD-4 and MD-1 sessions tend to place, with low dispersion, the players in a "low EL and IL" zone, guaranteeing a recovery process, especially if combined with an optimal well-being status (Gabbett et al., 2017). On the contrary, in MD-3 and MD-2 sessions, as well as in MD, in which higher loads were recorded, most of the players were placed in a "high EL and IL" zone with a tendency towards dispersion towards the fitness or fatigue zones. This indicates that when players are exposed to high loads, and although most of them will exhibit an expected outcome response ("high El and IL"), the chances of having an unexpected response that would represent an improved fitness status or a fatigue process might be increased. Although this is beyond the scope of this study, such individual unexpected responses (fitness and fatigue) merit further attention in order to individualise the training process better by adjusting training loads and modifying training content.

## Differences Between Sessions in the Microcycle

The second aim of this study allowed us to compare training sessions and match EL and IL. One of the main findings was that in the MD-4 training sessions, all EL variables and s-RPE were below the match and MD-3 and MD-2 training sessions, but declared RPE was not different from the match and MD-3 and MD-2 training sessions. The differences in IL metrics (s-RPE vs. declared RPE), as previously stated, can be explained by the difference in definition of the metrics: a nominal intensity score reported by declared RPE versus the inclusion of the duration of the session in s-RPE. Moreover, this specific difference in MD-4 sessions and the rest of the sessions might also be accounted for by the fact that the players were exposed to the longest weekly (45 min) coadjuvant strength training (Gómez et al., 2019) at the gym followed by in-court sessions focusing on SSG (**Figure 1A**). Therefore, coadjuvant strength training in the gym just before the beginning of the specific training session could have had an impact on the declared RPE measured. This content training arrangement has been defined as concurrent training (Fyfe et al., 2014), which might have an effect on EL variables of the specific in-court part of the session (lowering the load) and an effect

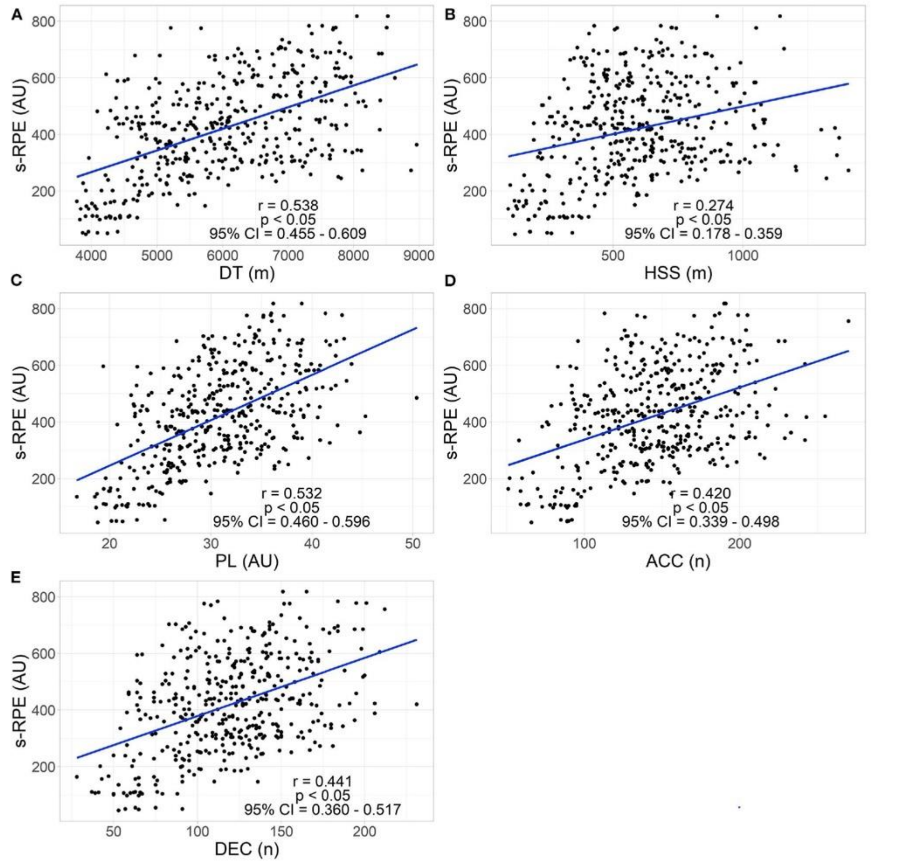


**FIGURE 2** | Correlation between EL metrics and session RPE (s-RPE). **(A)** s-RPE and distance travelled. **(B)** s-RPE and high-speed skating distance. **(C)** s-RPE and Player Load. **(D)** s-RPE and number of high-intensity accelerations. **(E)** s-RPE and number of high-intensity decelerations. DT, Distance travelled; HSS, High-speed skating; PL, Player Load; ACC, High-intensity accelerations; DEC, High-intensity decelerations; s-RPE, Rate of perceived exertion × total duration of session.

on the declared RPE (increasing the load), but not on the s-RPE because of the shortert in-court training time. In line with our results, Enright (2014) showed that in soccer, when resistance training was performed before specific soccer training, the specific training declared RPE was significantly higher than the inverse training sequence. Although several mechanisms may account for the difference between IL variables, none of them alone can definitely justify the results. However, knowing the reality of IL and EL dynamics can help staff members to take decisions to optimise MD-4 sessions loads, for example in this specific scenario, separating the strength session from the in-court session (into morning—afternoon sessions) would allow for a greater recovery between sessions that would mean that the perception of effort of the first session did not excessively affect the second one.

Another relevant finding regarding MD comparison was that MD-3 and MD-2 training sessions presented the greatest load demands compared to MD. MD-3 training sessions were superior in DT, ACC, and declared RPE, although no significant differences were found between HSS, PL, DEC, and s-RPE compared to MD; MD-2 sessions were significantly superior in DT; equal in HSS, declared RPE and s-RPE and significantly lower in PL, ACC, and DEC with regard to MD (**Table 3**). These results were similar to those reported by Illa et al. (2020) in futsal, where EL was equal to or greater than MD in the central part of the microcycle but different to outdoor team sports, such as soccer (Stevens et al., 2017; Martín-García et al., 2018), where it proved impossible to reach MD levels in the training sessions and especially in MD-2 training sessions. Unlike indoor team sports, more time may be required to recover from intense pre-match training sessions in outdoor team sports, and for this reason most of the training load was prescribed between MD-4 and MD-3 sessions. The training contents prescribed in MD-3 and MD-2 training sessions described in **Figure 1A** could explain the greater load demands in EL and IL (in some metrics); in line with this, some research in basketball (Vazquez Guerrero et al., 2018) suggests that the bigger the space used in specific in-court drills the greater the EL imposed upon the players. The use of roller skates in rink hockey makes it easy to move around the court and more difficult to remain motionless in one place, and this could be a reason for the higher absolute values of distance, and high-speed distance than in other indoor sports (Fernández et al., 2020b). Another interesting point is that DEC is a variable that is always lower on training days than on the match days (or at most equal). The main point is that, as mentioned in the introduction, DEC in rink hockey may be the variable that makes a difference; for example, when a player returns from an attacking phase to a defensive phase an intense and short deceleration may make the difference between a good defensive transition (timely, fast, and effective) and a bad one (late and tactically un—successful). Finally, as described in **Figure 1C**, all EL and IL metrics (based on the s-RPE metric) presented a major dispersion in MD-3 and MD-2 sessions, albeit with a tendency to be in the "high EL and high IL" quadrant, particularly MD-3 sessions.

Finally, with regard to MD comparison, it is also interesting to emphasise that there was a decrease in all the variables studied as match day approached (MD-1 sessions). The consistent finding of a reduction in MD-1 training sessions of EL and IL denotes a tapering strategy to guarantee freshness before competition. Many studies in team sports have demonstrated that this strategy is effective in ensuring that players will be totally competition-fit (Akenhead et al., 2016; Los Arcos et al., 2017; Owen et al., 2017; Martín-García et al., 2018; Illa et al., 2020). More specifically, if we examine competitive match loads in the weekly load dynamic, considering them as an important factor that conditions the other training sessions (Tarragó et al., 2019); then the MD-1 sessions tapering strategy in team sports consists of lowering EL and IL, ensuring recovery and guaranteeing players' match readiness (Svilar et al., 2019). In summary, and as described in **Figure 1C**, MD-1 presented a "low EL and low IL" profile with a low data dispersion, ensuring a consistent tapering strategy in the team analysed.

### Correlation Between EL and IL

The third and final objective of this research was to examine the correlations between EL and IL. The analysis of the relationship between the EL variables studied and the s-RPE IL metric is presented in the **Figure 2**. The correlations studied in the team analysed ranged from high to low in all the metrics selected; DT and PL were the two variables with the highest values of correlation with s-RPE with high values; HSS was the lowest correlated variable with s-RPE with low results. The volume metrics (DT and PL) findings are in line with those of Scanlan et al. (2014) in basketball, who found that the relationship between accelerometer training load data (similar to PL metric) and s-RPE was very similar to the correlation of our research. In contrast, field-based team sports presented stronger relationships between volume EL metrics and IL (Burgess et al., 2006; Scott et al., 2013) than indoor team sports. On the other hand, high-intensity metrics such as HSS presented the lowest correlation with IL, suggesting, on the one hand, and in line with Fernández et al. (2020b), that high-speed movement may be maintained through the use of inertia from a previous effort and not through the player's continual effort, whereby the HSS metric does not account for the players' entire internal response; and on the other hand, in line with Scott et al. (2013), that as the speed of EL criterion increases (the HSS threshold was 18 $km \cdot h^{-1}$), the strength of its relationship with s-RPE becomes weaker. Modern rink hockey is based on a very high pace of skating and of ball possession (Perez, 2017). In addition, professional teams seek faster offensive and defensive transitions, which probably increases the HSS volume per match as in soccer, where high—speed running distances have increased in recent years (Bush et al., 2015). This suggests the need for more research into HSS and its degree of correlation with IL and also, into absolute and relative thresholds in HSS. Finally, the results of the correlation analysed suggest that not only do EL variables affect IL response, but also that individual characteristics, psychological status, health, nutrition and the environment, among other intrinsic and extrinsic factors, could affect this response (Impellizzeri et al., 2019). Therefore, taking the different degree of association between EL and IL metrics (ranging from high-to-moderate for volume EL metrics and s-RPE and moderate-to-low for intensity EL metrics and s-RPE) into account, both variables should be measured, since they offer complementary information about conditional demands and elite rink hockey players' response to these demands, respectively.

## CONCLUSIONS

This research, the first of its kind with an elite rink hockey team, presents an integrative approach to the EL and IL of players for monitoring fitness and fatigue status during a standard microcycle. As a skating sport, DEC in rink hockey could be the variable that make a difference in match situations, possibly being this the reason why DEC was the only (along with HSS) EL variable that did not surpass the match volume during a standard microcycle. An inverted "$U$-shape" load dynamics with a load peak between MD-3 and MD-2 sessions, a mismatch between declared RPE and s-RPE metric in MD-4 sessions and a high correlation between volume EL variables and IL (s-RPE) were the most important findings in this team's microcycle. This could provide team sport staff members (coaches, strength and conditioning coaches, and physicians) with a deeper understanding of load distribution throughout the microcycle. The use of $z$-scores analyses integrating EL and IL builds up an objective decision-support tool for changing and adapting training loads and content. This study is based on a single elite rink hockey team with international top-level players, and the findings provide a basis for the quantification of a standard microcycle, constituting a point of departure for other research into EL and IL in this sport as well as in other team sports.

## DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the ethics committee for clinical research of the Catalan Sports Council 29/CEICGC/2020. The patients/participants provided their written informed consent to participate in this study.

## AUTHOR CONTRIBUTIONS

DF participated in the design of the study, contributed to data collection, reduction, analysis, interpretation of results, and contributed to the manuscript writing. DM participated in the interpretation of results and contributed to the manuscript writing. JC contributed to the manuscript writing. GC participated in the design of the study, contributed to interpretation of results, and manuscript writing. All authors have read and approved the final version of the manuscript and agree with the order of presentation of the authors.

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**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## 18. Publicació article científic 3

The distribution of different intensity demanding scenarios in elite rink hockey players using an electronic performance tracking system

D. Fernández, J.A. Cadefau, N. Serra, G. Carmona.

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RESEARCH ARTICLE

# The distribution of different intensity demanding scenarios in elite rink hockey players using an electronic performance tracking system

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**Data Availability Statement:** All relevant data are within the paper and its Supporting information files.


## Abstract

Despite the traditional use of average values for determining physical demands, the intermittent and fluctuating nature of team sports may lead to underestimation of the most demanding scenarios. All the most demanding scenario-related investigations to date only report one maximal scenario per game, the greatest. However, the latest research on this subject has shown additional scenarios of equal or similar magnitude that most researchers have not considered. This repetition concept started a new way of describing competition and training loads; then the study aims were: first, to quantify and assess differences between playing positions in terms of the most demanding scenarios in official matches; and second, to quantify and assess the differences between playing positions in the repetition of different intensity scenarios relative to the most demanding individual scenario. We monitored nine professional rink hockey players (7 exterior and 2 interior players) in 18 competitive matches using an electronic performance tracking system. The interior players are closest to the opponent's goal, while the exterior players are farthest from it. Peak physical demands variables included total distance (m), distance covered at >18 $km{\cdot}h^{-1}$ (m), the number of accelerations ($\geq 2\ m{\cdot}s^{-2}$, count) and decelerations ($\leq -2\ m{\cdot}s^{-2}$, count) in 30 s. An average from the top three individual most demanding scenarios was used to define a reference value to quantify the distribution scenario repetition during matches. The results showed that peak demands in rink hockey are position-dependent, with more distance covered by exterior players and more accelerations performed by interior players. In addition, rink hockey matches include multiple scenario exposures that are close to the peak physical demands of a match. Using the results of this study, coaches can prepare tailored training plans for each position, focusing on distances covered or accelerations for exterior players.


## Introduction

Rink hockey is a dynamic and complex indoor team sport in which players use roller skates to perform intermittent and multidirectional actions, such as accelerations, decelerations, sprints,

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and impacts. All these actions are performed in a sport-specific framework of driving, shooting, passing, blocking, and defending. Roller skating makes rink hockey a dynamic and fast sport that has relative average demands far greater than other indoor sports [1, 2]. Actually, there has been a trend in growth of the use of inertial devices combined with ultra-wide band (UWB) positioning technology to track distance, accelerations, and decelerations during matches and training sessions. Rink hockey has not escaped this, and information about physical and position-related demands can guide sports scientists in rink hockey in the improvement of training programmes and the use of accurate training loads that minimise the risk of injury [3]. Research comparing different team sports [4] showed that rink hockey along with soccer achieves the greatest values in total distance and distance above 18 km/h; and along with basketball achieves the greatest values in the number of accelerations and decelerations. Finally, other research on external loads in official rink hockey competitions has shown that no differences exist between playing positions (exterior and interior players) in the average physical demands imposed by matches [1, 2]. After that, coaches could use that information to plan and prepare the training microcycle, and the individual training sessions for players; as rink hockey is a high intensity sport without any differences between positions in terms of average demands.

However, the approach used to assess average physical demand underestimates peak intensities during indoor or outdoor matches due to the intermittent nature of team sports [5]. Some peak moments may be hidden by the average values of all game signals. For this reason, it is necessary to use other monitoring methods to determine the most demanding scenarios (MDS), a period of peak demands experienced by the players during a match, and to implement proper training intensities during sport-specific drills [6].

There has been a growth in research using rolling or moving averages [7] to examine peak competition demands in team sports based on identifying the MDS, also referred to as the most demanding passages in the literature [8, 9]. This new approach provides important results that may complement the previous research that mostly focussed on average physical demands. Monitoring the MDS using moving averages helps scientists and coaches understand the parameters that are more important in the analysis of team sports loads because this measure takes into account the naturally intermittent nature of team sports, where, due to the variability of the matches, it is expected that some moments will be more intense than others [10].

Research into peak demands during different epochs (frequently 30 and 60 s) has been conducted using rolling average methods in soccer [11], rugby [12], basketball [6, 13], futsal [14], and rink hockey [8]. To date, all the cited investigations only report one maximal scenario per game, with the latest MDS research [9, 15] showing additional scenarios of equal or similar magnitude that most researchers and sport scientists did not consider in a given match. The approach of only describing one MDS and not all the different intensity scenarios could underestimate the overall physical demands that occur in a match (e.g., it could be that a player must cope with more than 4 or 5, 30 or 60 s scenarios, near to the MDS). This concept was first described in the literature as the repetition of high (80%–90% of the MDS), or very high (>90% of the MDS) demanding scenarios [9]. Finally, the repetition of scenarios to study the distribution of physical activities in team sports is rare in sports science, and to the authors' knowledge, studies have only reported the distribution of maximal and submaximal demands relative to the peak intensities in basketball matches [16], futsal matches [9, 15], and rugby and Australian rules football matches [17, 18]. To date, no study has described the distribution of different scenarios of relative intensity in competitive rink hockey and this study aims to do it.

In this study, we have aimed to quantify and assess differences between playing positions in terms of the MDS in official matches. In addition, we have aimed to quantify and assess the differences between playing positions in the repetition of different intensity scenarios relative to the individually most demanding scenario. Based on the previous literature in rink hockey, the hypothesis of this study was that interior players experience the same MDS and repetition of different intensity scenarios as the exterior players.

## Materials and methods

### Design

We conducted an observational retrospective study in a cohort with a time of follow-up of 2 years during the 2019–2020 and 2020–2021 competitive seasons. In 2019–2020, we were forced to stop in March 2020 due to COVID-19. External load was measured by a UWB electronic performance tracking system (WIMU PROTM, Realtrack Systems, Almeria, Spain) during 18 official matches of a professional team in the highest Spanish tier (Ok Liga), and that also participated in the WSE Rink Hockey EuroLeague.

### Subjects

Nine professional elite outfield players (age 29.0 ± 5.22 years, weight 78.8 ± 6.20 kg, height 180.6 ± 3.91 cm; all measurements in mean ± standard deviation) participated voluntarily. Goalkeepers did not participate in the study due the goalkeeper's own characteristics and the great technical difference compared to court players. Data from each player and match had to meet two inclusion criteria: (1) players finished the match without injury; and (2) players participated in the entire pre-match training session to ensure that we only included players who had prepared for the match the day previously. The nine players were comprised of seven exteriors and two interiors, as determined by three qualified rink hockey coaches (all of whom had national level certificate in rink hockey coaching from the Spanish Skating Federation, as well as at least three years' experience coaching teams in national leagues). In the possession phase, exterior players are those who play far from the opponent's goal with a lot of mobility, while interior players are those who play closest to the goal with less mobility and less space. To compare average per game scenarios between positions we checked that all analysed players did not have significant differences in the minutes played per game. The data which were analysed arose from routine daily monitoring of activities during the season. The ethics committee for clinical research of the Catalan sports council approved the experimental procedures used in this study (29/CEICGC/2020), and all the players provided informed consent before participating.

### Procedure

All matches were completed on the same official sport-specific indoor court in similar environmental conditions (court material, temperature, light, facilities. . .) and during in-season weeks. All players completed a standard 45-minute warm-up comprising dynamic mobility and individual sport-specific skills, such as passing, shooting, dribbling, and playing a small-sided game. Although the players were continuously monitored throughout the warm-ups and total match time, we only analysed data from when players were competing on court. We removed all resting data that was collected after substitutions and between periods.

Each player wore the same micro-technology positioning system device (81 × 45 × 15 mm, 70 g) throughout to reduce potential inter-unit variability [19]. The WIMU PRO™ units are equipped with four 3D accelerometers (full-scale output ranges are ± 16 g, ± 16 g, ± 32 g, ± 400 g, at 100 Hz sample frequency), three gyroscopes (8000º/s full-scale output range, at 100 Hz sample frequency), a 3D magnetometer (100 Hz sample frequency), a global positioning system (10 Hz sample frequency), and a local positioning system with UWB technology (18 Hz sample frequency). For better signal emission and reception, six UWB antennas were installed on the rink hockey court to form a hexagon (with a sampling frequency of 18 Hz for the positioning data). Recently, the WIMU PRO™ system presented a high intra-class correlation coefficient value for the x-coordinate (0.65), a very high value for the y-coordinate (0.85), and a good percentage technical measurement error of 2.18% [20].

We included four physical demand parameters to describe the MDS and distribution of match activities. These included the following: distance travelled in meters (DT; m); high-speed skating; distance covered >18 km/h, in meters (HSS >18 km·h−1; m); number of high-intensity accelerations (ACC; >2 m·s−2; count); and number of high-intensity decelerations (DEC; >2 m·s−2; count). All these variables were chosen for two reasons: first, they were the ones most commonly used in other descriptive studies of competition loads in indoor sport research, and the thresholds used were the ones most commonly used in other external load research studies on rink hockey [1, 2, 4, 8], which allowed us to compare our results with previous literature, and second, it is a starting point in this kind of literature for further research on both variables and thresholds. After each match, data from the local positioning system were downloaded and extracted using the manufacturer's software (SPRO™, Realtrack Systems SL, version 977). The software provided instantaneous raw data as a rolling average for each variable and player over 30 s epochs. This specific epoch was chosen because it has already been used in previous research [5, 15], and could therefore be used to compare common average physical demands during competition.

We extracted the MDS data from the rolling average data for each player, variable, and match; and computed the distribution of the relative physical activities using a two-step process for each player and variable [9, 15]. At first, we determined an individual reference value (100% MDS reference value) from the mean of the top three observations per player using the 18 matches sample. That top three observations mean (instead of taking the maximal MDS recorded) had the main goal of avoiding any extreme value that was real in competition (because it was recorded) although it was too unrealistic to happen almost every match, whereas to smooth possible outliers. This is the reason why in the results section, some 30 s scenarios are above 100% of the individual MDS. These individual reference values are presented in Table 1 and compared with the mean MDS of all matches. In the second step, we re-analysed all matches searching all the 30 s scenarios in the rolling average data, transforming the absolute values to relative ones using the maximal reference values likewise in internal load studies the heart rate is expressed through relative values related to the individual's maximal heart rate. Thereafter, we established 10% buckets, counting the number of scenarios in each bucket. The final output was the total number of scenarios per each bucket, player, and variable. All the previous procedures are summarized in Fig 1.

## Statistical analysis

All statistical analyses were conducted with RStudio version 1.3.1093 (RStudio, Inc.). MDS descriptive data and the number of scenarios per bucket are reported as means ± standard deviations. Sample size analysis was not conducted due to the use of the bootstrap method approach and its assumptions about sample size (bootstrap is a suitable method when the sample size is small) [21]. We conducted an exploratory analysis using boxplots to identify possible outliers of the data. To assess the differences between positions, we used a bootstrap confidence interval approach for MDS and the number of scenarios per bucket [21, 22]. A re-sampling model, with 2,000 bootstrap samples and a 95% bias-corrected and accelerated method, was used to calculate the confidence intervals of *t*-test values for each variable. This established

**Table 1. Individual reference of the most demanding scenario values for each player extracted from all the games analysed, with the overall means, by position, in 30 s time epochs.**

| Position | Player | DT (m) | | HSS (m) | | ACC (count) | | DEC (count) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Top 3 | all | Top 3 | all | Top 3 | all | Top 3 | all |
| Exterior | P1 | 126 | 119 | 62.7 | 49.5 | 6.67 | 5.83 | 7.00 | 5.83 |
| Exterior | P2 | 145 | 134 | 88.2 | 70.4 | 8.00 | 6.72 | 8.00 | 6.67 |
| Exterior | P3 | 142 | 132 | 81.2 | 65.1 | 6.67 | 6.00 | 6.00 | 5.50 |
| Exterior | P4 | 137 | 126 | 73.0 | 57.5 | 8.00 | 6.56 | 7.33 | 6.00 |
| Exterior | P5 | 147 | 132 | 93.7 | 67.7 | 6.33 | 5.44 | 6.00 | 5.00 |
| Exterior | P6 | 122 | 122 | 51.2 | 51.2 | 6.00 | 6.00 | 6.67 | 6.67 |
| Exterior | P7 | 137 | 124 | 77.3 | 55.0 | 6.67 | 5.89 | 6.33 | 5.67 |
| | mean | 136 | 127 | 75.3 | 59.5 | 6.90 | 6.06 | 6.76 | 5.90 |
| | SD | 9.46 | 5.79 | 14.6 | 5.25 | 0.79 | 0.44 | 0.74 | 0.61 |
| Interior | P8 | 136 | 124 | 71.2 | 54.2 | 7.33 | 6.61 | 7.33 | 6.11 |
| Interior | P9 | 132 | 126 | 76.0 | 60.5 | 7.67 | 6.50 | 7.33 | 6.06 |
| | mean | 134 | 125 | 73.6 | 57.4 | 7.50 | 6.56 | 7.33 | 6.09 |
| | SD | 2.69 | 1.53 | 3.42 | 4.44 | 0.24 | 0.08 | 0.00 | 0.03 |

Note. Data shows mean of the top 3 MDS results for each player with the overall means and SD by position. Abbreviations: ACC, high-intensity accelerations; DEC, high-intensity decelerations; DT, distance travelled; HSS, high-speed skating; MDS, most demanding scenarios; SD, standard deviations.

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the null hypothesis, that there were no differences between positions, and the mean difference between positions was computed and presented as standardised differences (Cohen's *d*). Thresholds for standardised differences were <0.20) for trivial, 0.20–0.59 for small; 0.60–1.19 for moderate, 1.20–1.99 for large, and >2.0 for very large [23]. All reported p-values reflect the likelihoods of observing the absolute effect sizes assuming a true null hypothesis of zero

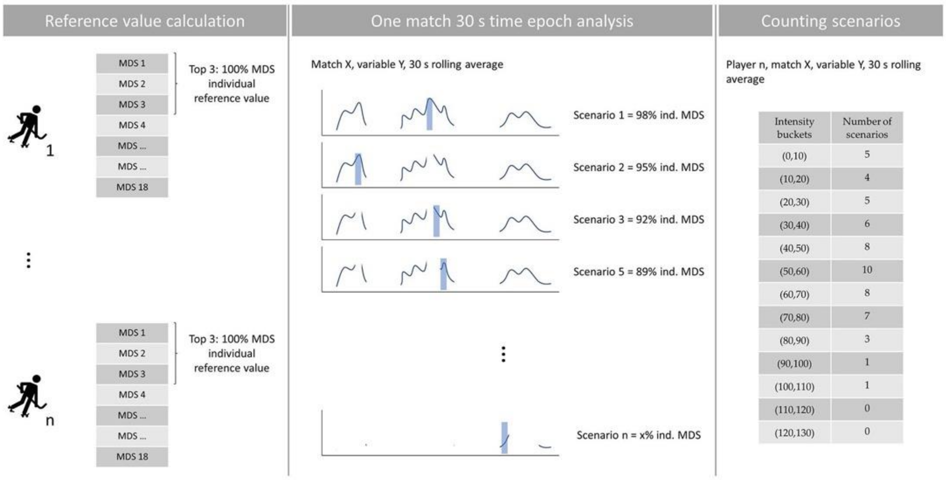


**Fig 1. Brief schematic representation of methodological procedures used to calculate: The individual reference values (left panel), all the scenarios in one match (central panel), and how the scenarios are counted (right panel).** Abbreviations—MDS: most demanding scenario.

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difference [24]. Differences are presented with Cohen's *d* for the effect size and their corresponding 95% confidence intervals.

## Results

Table 2 summarises the descriptive results for the MDS, and Fig 2 shows the hypothesis test results for the MDS. Interiors had greater ACC with significant but small effect sizes.

Fig 3 and Table 3 show the descriptive results for the number of scenarios per bucket and variable per match. The DT variable had a greater number of repetitions in the central area of the buckets (between 60%–70% and 70%–80%); the HSS variable had a repetition peak in the first buckets; and the ACC and DEC variables had the greatest number of the scenarios between the 10% and 40% buckets.

Standardised differences (Cohen's d) and 95% confidence intervals between playing positions are presented in the Fig 4 for all variables and buckets. Exterior players did significantly more scenario repetitions in some buckets for the HSS variable, but with a small effect size. By contrast, both interiors and exteriors showed significant moderate differences in repetition scenarios for the ACC and DEC variables in different buckets and in different and unclear directions.

## Discussion

The present study aimed to quantify and assess differences between playing positions in terms of the MDS in official matches. In addition, it aimed to quantify and assess the differences between playing positions in the repetition of different intensity scenarios relative to the individually MDS. We found that the MDS demands during elite competition, although small to trivial, differed by player position in the ACC variable. In addition, rink hockey players were found to be exposed to different intensity 30 s scenarios that repeated more than once depending on their intensity and the metric analysed; exterior players did significantly more scenario repetitions in some buckets for the HSS variable, but with a small effect size.

### Quantification of the MDS and the differences between positions

A major finding of this study was the quantification of peak physical demand, understood as the MDS in competition. The activity profile described in the current investigation and elsewhere [5, 6] seems much more demanding than reported in a previous rink hockey study [2] that used average measures instead of rolling average epochs. The latter study found that players averaged 129–132 $m \cdot min^{-1}$ for DT, 24.8–26.8 $m \cdot min^{-1}$ for HSS, 4.8 $count \cdot min^{-1}$ for ACC, and 4.5 $count \cdot min^{-1}$ for DEC. Our investigation indicates that rink hockey had higher MDS values in 30 s time epochs compared to all these averages. In accordance with Vázquez-Guerrero et al. [6], our results improve coaches and sport scientists' understanding of the demands

**Table 2. Most demanding scenarios descriptive results by variable and position.**

| Epoch | Variable | Exterior | Interior |
|---|---|---|---|
| 30 s | DT (m) | 127 ± 9.28 | 125 ± 6.23 |
| | HSS (m) | 60.5 ± 14.3 | 57.2 ± 10.4 |
| | ACC (count) | 6.07 ± 0.87 | 6.56 ± 0.75 |
| | DEC (count) | 5.81 ± 0.89 | 6.09 ± 0.90 |

Note. Data show means ± standard deviations. Abbreviations: ACC, high-intensity accelerations; DEC, high-intensity decelerations; DT, distance travelled; HSS, high-speed skating; MDS, most demanding scenarios.

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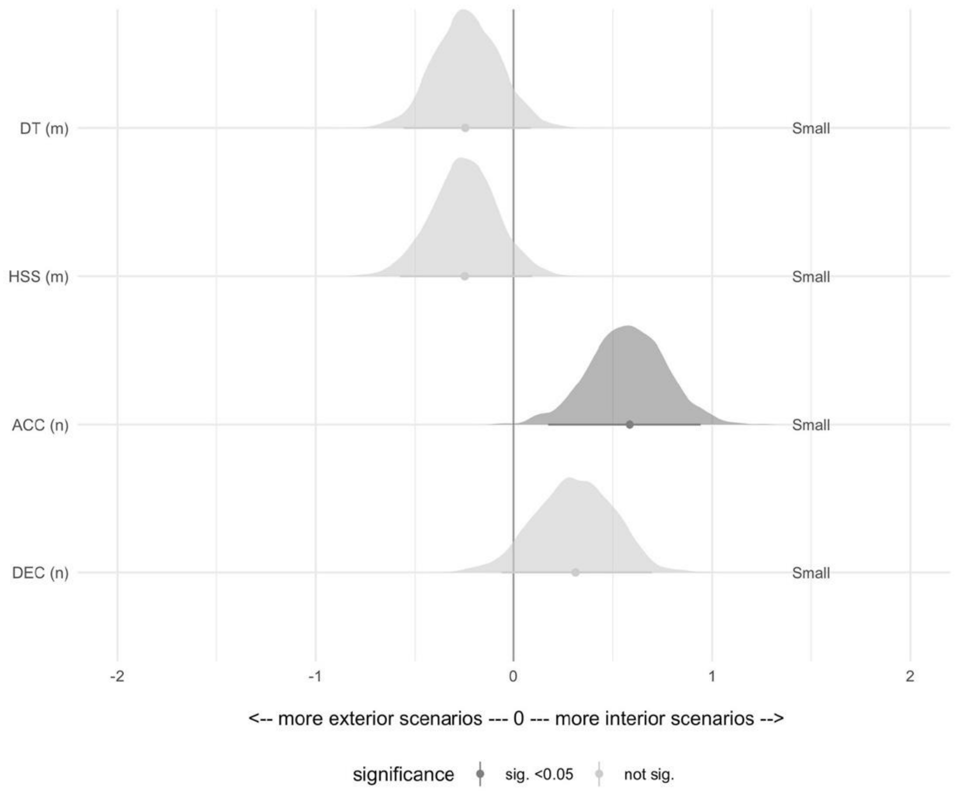


**Fig 2. Pairwise Cohen's d differences in the most demanding scenarios (time epoch 30 s) of a match by playing position for each variable.** The significant different variables (high-intensity accelerations) are shown in dark grey, and the non-significant (distance travelled, high speed-skating and high-intensity decelerations) in light grey. Abbreviations—ACC: high-intensity accelerations; DEC: high-intensity decelerations; DT: distance travelled; HSS: high-speed skating; MDS: most demanding scenarios.

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of competition, and will help them design more accurate training drills that achieve peak demands and mitigate the risk of injury. Individual training sessions can be an example of how MDS knowledge can be useful. The creation of tasks that simulate different MDS that can be found in matches using different variables can be another way (obviously, not the only one) to schedule and prepare exercises. This enhances the training sessions.

After comparing the peak and average demands of rink hockey, it could be interesting to perform comparisons with other team sports to examine rink hockey in its wider context. The peak demands in rink hockey were higher than in outdoor sports like soccer [11] and rugby [12], except for DT and HSS, where the demands were similar. For indoor sports like basketball [6, 13] and futsal [14] we found peak demands in rink hockey to be greater for all the analysed metrics, except for ACC and DEC in futsal, where the demands were similar. In comparison with outdoor sports, the results of indoor sports are more interesting because of

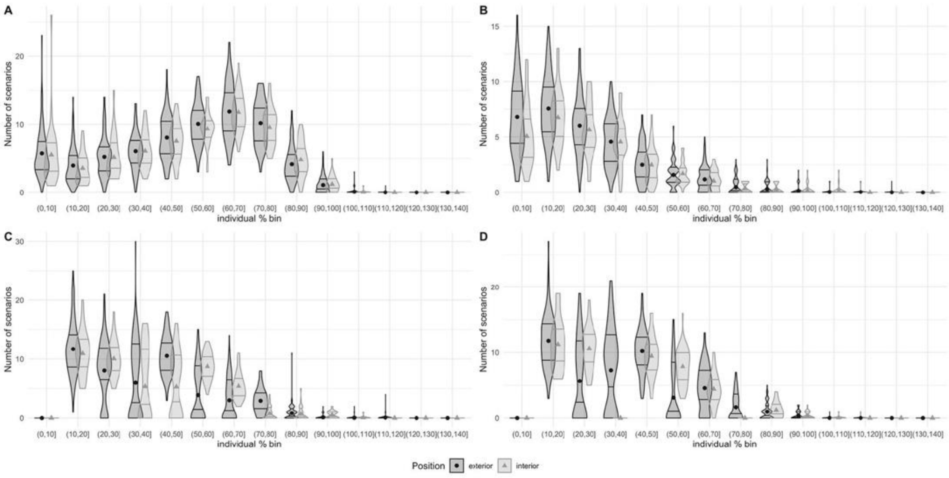


**Fig 3. There is a graphical descriptive number of 30 s scenarios (mean, quartile 1 and quartile 3) in a match for each intensity bucket for each variable.** Exterior players are shown in dark grey and interior players in light grey. A: distance travelled; B: high-speed skating; C: high-intensity accelerations; D: high-intensity decelerations.

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the significant differences in the number of players or the space compared with outdoor sports. As reported by Fernández et al. [1], the use of roller skates and fences in rink hockey could account for the higher average values and peak demands of DT and HSS compared to basketball and futsal.

Finally, we found that the MDS data are position-dependent for the ACC metric, albeit with small magnitudes of difference. Interior players performed a greater number of accelerations (from 5.81 to 6.09 ACC per 30s scenario between interior and exterior players) in the MDS of matches. This significant difference may be relevant when prescribing a training programme, despite the low magnitude of effect. As with other indoor sports, the inherent requirements of each position in games and a team's playing model could explain these results [25]; there could be less space for interior players in rink hockey, so they may require more reception and rebounding movements, or press after losing possession of the ball in another court, defend in own court, or support in spaces with high player density by doing more change-of-directions, stops, and other sharp movements. These difference have not been reported for the average demands of competition, where the only published research to date found no significant differences between positions in absolute or relative variables because of the fast and dynamic nature of the sport studied [2]. Therefore, it may be that no significant differences exist in accumulated external load between exteriors and interiors, but that these demands are sensitive to the player's position during the MDS of competition but in a small magnitude. This information can help coaches improve their training tasks. With a range of options as large as adding conditioning blocks focused on the specific demands of specific positions (i.e., interior players), up to changing rules, number of players or spaces in small-sided games (i.e., reducing the space of the court as literature about small-sided games demonstrates that is a variable that highlights the ACC and DEC demands [26]).

**Table 3. Descriptive results of the repetitions number of 30 s scenarios by interior and exterior players for each bucket and variable per match.**

| Position | Bucket | DT | HSS | ACC | DEC |
|---|---|---|---|---|---|
| Interior | (0,10) | 5.53 ± 4.48 | 5.06 ± 2.70 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| | (10,20) | 3.53 ± 2.14 | 6.76 ± 2.40 | 10.9 ± 3.58 | 11.8 ± 4.01 |
| | (20,30) | 5.18 ± 2.94 | 5.65 ± 2.37 | 10.1 ± 2.89 | 5.66 ± 6.02 |
| | (30,40) | 6.09 ± 2.47 | 4.56 ± 2.09 | 5.35 ± 6.11 | 7.30 ± 6.24 |
| | (40,50) | 7.53 ± 2.64 | 2.47 ± 1.58 | 5.29 ± 5.39 | 10.2 ± 3.20 |
| | (50,60) | 9.32 ± 2.38 | 1.71 ± 1.06 | 8.76 ± 2.22 | 3.12 ± 4.57 |
| | (60,70) | 11.8 ± 2.86 | 1.03 ± 0.90 | 5.41 ± 2.23 | 4.57 ± 3.28 |
| | (70,80) | 9.53 ± 2.68 | 0.35 ± 0.49 | 0.76 ± 1.10 | 1.68 ± 2.00 |
| | (80,90) | 4.79 ± 2.46 | 0.26 ± 0.45 | 0.71 ± 1.14 | 0.99 ± 1.19 |
| | (90,100) | 1.21 ± 1.15 | 0.18 ± 0.46 | 0.53 ± 0.61 | 0.38 ± 0.63 |
| | (100,110) | 0.06 ± 0.24 | 0.12 ± 0.41 | 0.09 ± 0.29 | 0.02 ± 0.14 |
| | (110,120) | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.02 ± 0.14 |
| | (120,130) | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| Exterior | (0,10) | 5.75 ± 3.45 | 6.82 ± 3.23 | 0.00 ± 0.00 | 0.00 ± 0.00 |
| | (10,20) | 3.92 ± 2.58 | 7.57 ± 2.86 | 11.7 ± 4.38 | 11.2 ± 3.76 |
| | (20,30) | 5.24 ± 2.89 | 6.04 ± 2.53 | 8.09 ± 5.03 | 10.6 ± 3.08 |
| | (30,40) | 6.07 ± 2.64 | 4.58 ± 2.18 | 5.98 ± 6.46 | 0.00 ± 0.00 |
| | (40,50) | 8.04 ± 3.22 | 2.49 ± 1.64 | 10.5 ± 3.15 | 9.44 ± 3.10 |
| | (50,60) | 10.1 ± 2.99 | 1.58 ± 1.19 | 3.90 ± 4.55 | 7.88 ± 2.83 |
| | (60,70) | 11.9 ± 3.86 | 1.18 ± 1.09 | 3.03 ± 3.47 | 4.41 ± 2.31 |
| | (70,80) | 10.2 ± 3.16 | 0.49 ± 0.74 | 2.94 ± 2.02 | 0.00 ± 0.00 |
| | (80,90) | 4.12 ± 2.51 | 0.31 ± 0.56 | 0.87 ± 1.30 | 1.24 ± 1.18 |
| | (90,100) | 1.10 ± 1.24 | 0.13 ± 0.37 | 0.13 ± 0.37 | 0.32 ± 0.53 |
| | (100,110) | 0.10 ± 0.38 | 0.04 ± 0.19 | 0.05 ± 0.25 | 0.06 ± 0.24 |
| | (110,120) | 0.01 ± 0.10 | 0.04 ± 0.19 | 0.08 ± 0.43 | 0.00 ± 0.00 |
| | (120,130) | 0.00 ± 0.00 | 0.01 ± 0.10 | 0.00 ± 0.00 | 0.00 ± 0.00 |

Note. Data shown means ± standard deviations. Abbreviations—ACC: high-intensity accelerations; DEC: high-intensity decelerations; DT: distance travelled; HSS: high-speed skating.

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## Quantification of scenarios' repetition relative to individual MDS and the differences between positions

To assess repetition, we divided the scenarios by relative intensity of an individual MDS. The resulting scenarios were categorised as low demand (<40% of individual MDS), moderate demand (40%–80%, MDS), high demand (80%–90%, MDS), and very high demand (>90%, MDS), according to previously published criteria [16]. This allowed us to determine the repetition of 30 s scenarios with different levels, depending on the intensity and the variable under investigation. Similar to our results, research regarding official futsal matches [15] concluded that high-demand and very high-demand scenarios occurred more than once in a variable-dependent manner. Results from basketball matches [16] indicates that scenarios recur across all intensities to different extents. Finally, research regarding rugby league and Australian rules football [17, 18] showed that scenarios of a moderate relative intensity recurred most during official matches.

Our methodology encourages a practical in-field use by counting the number of scenarios in each bucket across the intensity spectrum. This could be useful for providing coaches with reference data on the number of repetitions to programme into training drills to under- or

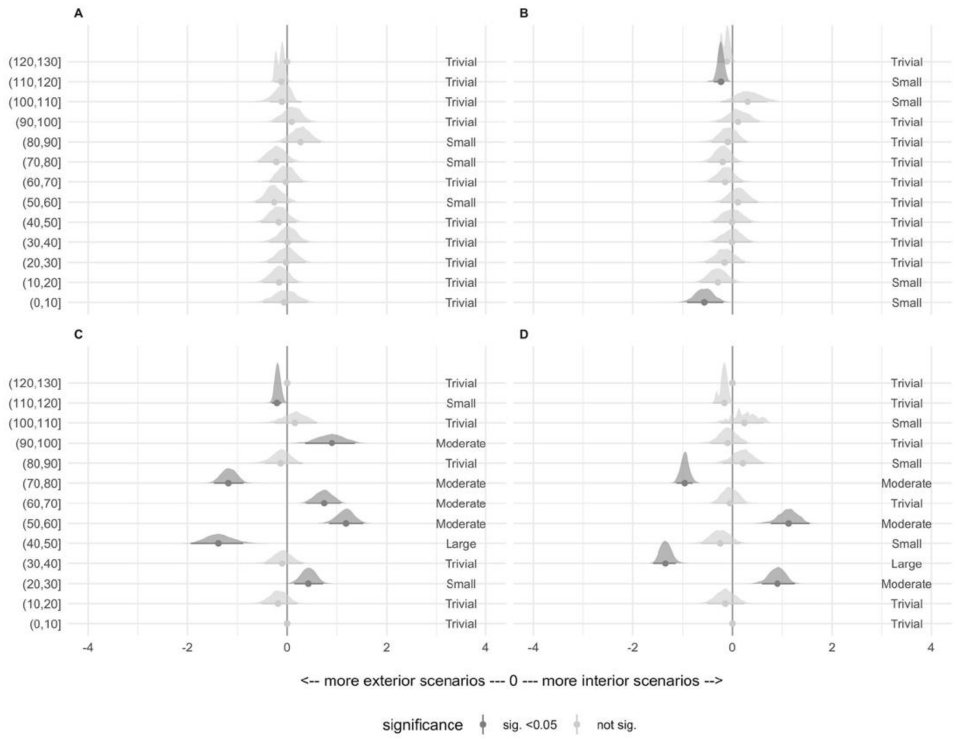


**Fig 4. Pairwise Cohen's d differences between positions for each match bucket per variable per 30 s.** The buckets with significant differences between positions are in dark grey, and the non-significant differences are in light grey. A: distance travelled; B: high-speed skating; C: high-intensity accelerations; D: high-intensity decelerations.

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over-stimulate the demands of the competition (e.g., doing 6 reps of a 30 s drill at approximately 70%–80% of an individual MDS DT will under-stimulate the match volume requirements in terms of scenario repetition). Volume-related variables (DT) had the greatest proportion of scenarios between 50% and 90% of the individual MDS, with a peak in the 60%–70% bucket. The higher the intensity criterion of the studied metric, the greater the proportion of scenarios that seem to accumulate in lower buckets. For example, the peak scenario repetition was in the 10%–40% bucket for ACC and DEC compared to the 10%–20% bucket for the HSS. So, in the analysed team, moderate- to high-demand scenarios were repeated most for volume-related variables, while low- to moderate-demand scenarios were repeated most for intensity-related variables.

When comparing the distribution of different scenarios, variables, and playing position, we observed multiple significant differences between exterior and interior players. Like the MDS results, our data revealed that exterior and interior players tend to be exposed to almost the same physical demands in low, moderately high, and very high-intensity buckets for the DT and HSS variables (except in two buckets of HSS). As with the MDS, one explanation could be that exterior and interior players had a fast, dynamic, and substantial exchange of positions in certain moments of matches. By contrast, interior and exterior players had stochastic differences in the number of scenario repetitions in ACC and DEC metrics only in most of the buckets. Again, as was the case for the MDS, interior players tend to perform more short actions in a confined space, which influences the number of moderate- and high-demand repetitions between interior and exterior players; but this tactical behaviour (short, fast, and sharp actions) does not affect in a clear way the results of our study. It could be that the study of different time epochs is necessary to find some more clear differences between player positions. To the best of our knowledge, this is the first study in rink hockey to consider playing positions when examining how match physical activities are distributed in relation to the MDS. Our results show that the distribution of physical activities seems not to be position-dependent during official competition by professional rink hockey players.

## Limitations

This research has some limitations. First, we collected data from only one professional team, resulting in a small, but exclusive, international, and professional sample. Second, we only examined the MDS and physical activity distribution relative to peak demands for 30 s. As shorter and longer time periods are also possible during a match, using 60, 120, 180, and 300 s epochs might yield more useful data. Third, this is a field pioneering research on the repetition of different intensity scenarios. Consequently, some procedures, such as calculating individual reference values, using intensity buckets, or using fixed time epochs, may require more investigation to find the best method that would allow a more accurate description of the competition. The distribution of preparatory activities regarding the MDS of a match during different training sessions (1, 2, 3, and 4 days prior to competition) should be considered in future research, as well as methodology improvements, to optimize the performance of individual players and teams.

## Conclusions

In conclusion, this research shows that rink hockey matches have higher 30 s peak demands than the averages reported in other research [2], and that these peak demands are position-dependent, with greater ACC values for interior players. Rink hockey matches also appear to include multiple exposures to (very) high-demand scenarios that are close to the peak physical demands of a match. We detected different scenario repetition distributions across all intensity buckets among the variables studied. Therefore, coaches and sport science professionals should consider the repetition of scenarios during training sessions based on the results. On individual interventions for example, interior players may also need a training stimulus increase for the ACC metric. Depending on the goal of training and the context within the season, adding more repetitions or a higher relative intensity based on the individual MDS may be appropriate.

From a practical perspective, the repetition of scenarios application allows coaches to program different intensity sets of fixed time epochs (which must be prescribed using the individual MDS reference) and determine whether the player is performing a volume below, equal, or above match demands. Moreover, this methodology allows to control the external load demands of the weekly training cycle, by using different intensity buckets (e.g., low, moderate, and intense) to determine which training session causes a greater repetition of intense scenarios, and whether it is above, equal, or below match demands. Alongside the lack of previous literature on this topic, our findings should stimulate the external load control future research, specifically, in rink hockey.

## Supporting information

**S1 File.**
(XLSX)

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## Author Contributions

**Conceptualization:** Daniel Fernández, Joan A. Cadefau, Gerard Carmona.

**Data curation:** Daniel Fernández.

**Formal analysis:** Daniel Fernández.

**Funding acquisition:** Noemí Serra.

**Investigation:** Gerard Carmona.

**Methodology:** Daniel Fernández, Gerard Carmona.

**Project administration:** Gerard Carmona.

**Software:** Daniel Fernández.

**Supervision:** Joan A. Cadefau, Noemí Serra, Gerard Carmona.

**Visualization:** Daniel Fernández.

**Writing – original draft:** Daniel Fernández, Gerard Carmona.

**Writing – review & editing:** Joan A. Cadefau, Noemí Serra, Gerard Carmona.

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# 19. Publicació article científic 4

Load demands in small-sided games in elite rink hockey External and internal load demands in small-sided games according to standard training games in elite rink hockey

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# External and internal load demands in small-sided games according to standard training games in elite rink hockey

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**Rink hockey | External load | Internal load | Training task**

## Headline

Small-sided games (SSGs) are useful tasks in modern training methodology, and a growth trend in both practical and scientific fields (1). In outdoor sports like soccer, the evidence is clear regarding the manipulation of pitch area. The larger the absolute and relative space, the more external load (EL) and internal load (IL) demands (1); only accelerations and decelerations were void of a significant relationship respect the pitch area (2,3). In rink hockey, the relationship between space and EL and IL is unknown.

## Aim

Therefore, the aim of our study was to quantify and assess differences in EL and IL between a standard training game format of 40 x 20 m versus a largely implemented training SSG drill in a format of 20 x 20 m training game.

## Design and methods

### Design

A retrospective observational study was carried out for the 2021-2022 season. A non-experimental descriptive method was used to identify the EL and IL demands in two different training game formats in this rink hockey professional team. EL was measured by an ultra-wide band (UWB) electronic performance tracking system (WIMU PRO$^{TM}$, Realtrack Systems, Almeria, Spain) and IL was measured using heart rate monitoring; all the data collected was later presented expressing the tasks demands relative to time ($m \cdot min^{-1}$, $n \cdot min^{-1}$ or $sec \cdot min^{-1}$). Data were collected throughout 17 weeks of in-season.

### Athletes

Elite male professional rink hockey players (n = 8, age: 28.5 ± 5.07 years, weight: 78.6 ± 4.13 kg, height: 180.8 ± 4.13 cm, all measurements mean ± standard deviation) participated voluntarily in the study, whereas the goalkeepers were excluded. At the time of the study, the team was holding between 4 and 5 practice sessions a week (between 1 and 1.5 hours) and was playing 1 or 2 matches a week. The data analyzed came from the daily player monitoring, in which player activities in court were routinely measured throughout all season. The experimental procedures used in this study were approved by the local Ethics and Scientific Committee (The Ethics Committee for clinical research of the Catalan Sports Council, 29/CE-ICGC/2020) and all the players signed an informed consent form before participating.

### Methodology

To compare different tasks, the activity profile of the players was monitored during each training session. Each player wore the same positioning system micro-technology device (81 × 45 × 15 mm, 70 g) throughout to reduce potential inter-unit variability (4). The WIMU PRO$^{TM}$ units are equipped with four 3D accelerometers (full-scale output ranges are ± 16 g, ± 16 g, ± 32 g, ± 400 g, at 100 Hz sample frequency), three gyroscopes (8000°/s full-scale output range, at 100 Hz sample frequency), a 3D magnetometer (100 Hz sample frequency), a global positioning system (10 Hz sample frequency), and a local positioning system with UWB technology (18 Hz sample frequency). For better signal emission and reception, installation on the rink hockey court comprised of six UWB antennas located to form a hexagon (sampling frequency of 18 Hz for the positioning data). The WIMU PRO$^{TM}$ system has been evidenced to have a high intra-class correlation coefficient value for the x-coordinate (0.65), a very high value for the y-coordinate (0.85), and a good percentage technical measurement error of 2.18% (5). For IL players wore a chest-worn heart rate monitor (Garmin HRM3-SS, Garmin Ltd., Olathe, USA). The heart rate monitor data was sent to WIMU PRO$^{TM}$, recorded at 18 Hz sample frequency, and treated together with the EL data.

The most standardized training game formats during the season were used to for the analysis. For instance, both were 4 vs. 4 players with goalkeepers in both teams. A 40 x 20 training game (TG40x20) was one of the analyzed tasks (area: 100 $m^2$ per player), and a 20 x 20 training game (TG20x20) was the other analyzed task (area: 50 $m^2$ per player). Both training games included official rules, but in the TG20x20 one of the sides were without fence (Figure 1) and every time the ball went out of bounds, a coach would put a neutral new ball in the court with the aim of avoiding stoppages. A total of 371 individual records (n = 329 for TG40x20 and n = 42 for TG20x20) were obtained. Analyzed game formats were conducted in the final part of the sessions. As the sample size reveals, the TG40x20 was a training game format that was used in a vast majority of the training sessions, and the TG20x20 was a training game format only used once in each microcycle.

The EL recorded variables were distance covered ($m \cdot min^{-1}$), distance covered at high-speed skating (>18 $km \cdot h^{-1}$, $m \cdot min^{-1}$), number of high-intensity accelerations (> 2 $m \cdot s^{-2}$, $n \cdot min^{-1}$), and the number of high-intensity decelerations (> 2 $m \cdot s^{-2}$, $n \cdot min^{-1}$). The IL recorded variable was the time spent above 90% of maximal heart rate (HRmax) ($sec \cdot min^{-1}$). All the EL intensity thresholds were established based on previous studies (6). As Abad et al (7) recommended in their research, we used the highest individual heart rate registered during all training and friendly games between August and December of 2021, as their methodology revealed its efficiency being comparable to maximal tests to calculate individual maximal heart rate.

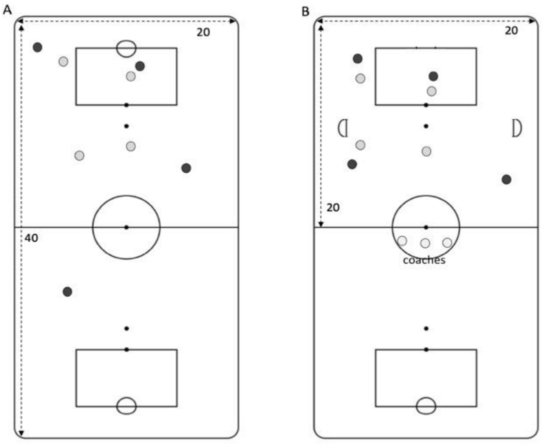


**Fig. 1.** **Court diagram of the training games. A: 40 x 20 training game (TG40x20), and B: 20 x 20 training game (TG20x20).**

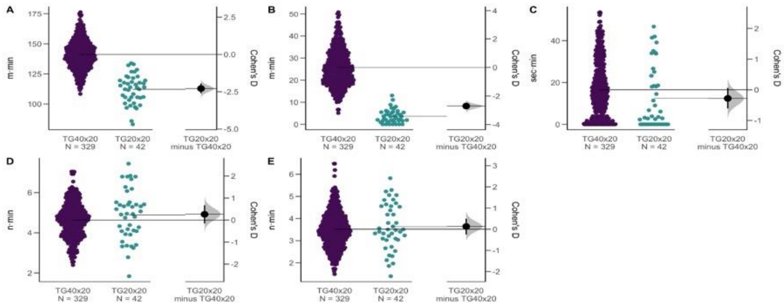

**Fig. 2. Distribution and Cohen's D differences between game formats in all the studied variables. A: Distance covered ($m \cdot min^{-1}$), B: High-speed skating ($m \cdot min^{-1}$), C: Time >90% HRmax ($sec \cdot min^{-1}$), D: High-intensity Accelerations ($n \cdot min^{-1}$) and E: High-intensity Decelerations ($n \cdot min^{-1}$). Note. TG40x20: Training game 40x20; TG20x20: Training game 20x20.**

## Statistical analysis

All statistical analyses were conducted with RStudio version 1.4.1103 (RStudio, Inc.). Descriptive results were reported as mean ± standard deviation. The assumptions for homogeneity of variance (Levene's test) and for normality Shapiro–Wilk test were violated. As a result, a bootstrap confidence interval (CI) approach was used to perform the hypothesis test to assess the differences between training games format (8,9,10). A residual resampling model with 5,000 bootstrap samples and 95% bias-corrected and accelerated method (BCa 95% CI) was used to calculate the CI of Cohen's D for each variable11. Thresholds for effect size (ES) statistics were (ES <0.20), trivial; (0.20 < ES <0.59), small; (0.60 < ES <1.19), moderate; (1.20 < ES <1.99), large; and (ES > 2.0), very large (12).

## Results

The descriptive results of the EL and IL variables from the two training games formats analyzed are displayed below in Table 1. The inferential analysis with bootstrapped resampling is presented in Figure 2. Results revealed that only distance covered ($p < 0.001$; ES 95%CI = 1.95-2.60), and high-speed skating ($p < 0.001$; ES 95%CI = 2.47-2.92) had significant differences between the two training game formats.

**Table 1. Descriptive results (mean ± standard deviation) of studied variables in different training games formats.**

| | 40 x 20 Training Game | 20 x 20 Training Game |
|---|---|---|
| Distance covered ($m \cdot min^{-1}$) | 141 ± 12.8 | 112 ± 12.0 |
| High-speed skating ($m \cdot min^{-1}$) | 25.8 ± 8.61 | 3.65 ± 3.10 |
| High-intensity Accelerations ($n \cdot min^{-1}$) | 4.63 ± 0.90 | 4.88 ± 1.26 |
| High-intensity Decelerations ($n \cdot min^{-1}$) | 3.51 ± 0.86 | 3.63 ± 1.04 |
| Time >90% HRmax ($sec \cdot min^{-1}$) | 16.5 ± 14.4 | 12.5 ± 14.9 |

## Discussion

The aim of this research was to quantify and assess differences in EL and IL between a standard training game (TG40x20) versus a SSG training drill (TG20x20). To the best of our knowledge, this is the first study to compare training game drills in rink hockey. Our results revealed large significant differences in distance covered and high-speed skating between tasks; but no differences in the number of accelerations, decelerations and the time spent above 90% of HRmax.

The absolute and the relative space reduction of the pitch size could be the principal reason that players cover less meters, and particularly at higher speeds. This could be due to the difficulty in achieving and maintaining high velocities in a smaller space with the same number of opponents (1). Our results are in line with previous research conducted in SSGs and pitch size, either outdoor or indoor sports (1,13,14) where the lesser space used, the lesser the distance covered.

On the other hand, the other studied variables did not reveal significant difference. Results showed that there aren't differences between TG20x20 and TG40x20 in high-intensity accelerations and decelerations, and time spent above 90% of HRmax. Starting with EL metrics, it seems that the space reduction doesn't affect the capacity of the players' high-intensity accelerations and decelerations, which could be due to the relative space used in the TG20x20 that entails a need for the players to perform the same amount of change of directions, reception movements and cuts equal to a normal game. The literature is incongruent in this respect, some studies have shown results in line with a non-reduction of these EL variables in SSGs in relation to a standard game (1), but other research have shown evidence that accelerations and decelerations decrease when the space is reduced (2,3). The internal load metric analyzed in this research did not reveal any significant difference between the two game formats, despite the space reduction. The IL of the task remained the same level of that of a standard game. Our findings, in conjunction with the EL findings encourages us to conjecture that the maintenance of similar values of high-intensity accelerations and decelerations between TG20x20 and TG40x20, is consistent with IL values. Research in soccer is well-defined in terms of the behaviour of internal load. The majority of studies reporting an increased heart rate, perception of effort and blood lactate concentration response with increased pitch area (15). Only Kelly & Drust (16) were the exception in that their study failed to find significant differences in heart rate peak between three different SSG formats.

To conclude, this research allows professionals of rink hockey to be cognizant of the effects of reducing the pitch size in a training game drill. It seems that the reduction of the space reduces the distance that players travelled, but yet still allow them to reach the same high-intensity accelerations, decelerations, and time spent above 90% of HRmax. This study's finding allows coaches to know what happens on the court when they manipulate training constraints such as pitch size. Finally, based on the work of Buchheit & Laursen (17), classification of metabolic and neuromuscular load in high intensity interval training, reducing space is a feasible application that concentrates on neuromuscular load.

## Practical applications

The findings of this study can be applied by coaching staff working directly with athletes and being mindful of the pitch size and its impact on EL and IL.

- It's interesting to point that the reduction of the space in the analyzed tasks didn't affect the IL intensity response of the players, noting that players had same effort levels doing less EL than in a standard match.
- Based on our findings, the use of the TG20x20 allow players to stimulate the neuromuscular system doing the same amount of high-intensity accelerations and decelerations, with less distance covered.
- Future studies would include increasing the relative pitch area (i.e., 3 vs. 3 in 40x20 meters pitch), as it would be interesting to examine if that would increase the IL response.

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## Declaration of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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