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Principal component analysis identifies different representative match load profiles in international women's field hockey based on playing positions

El análisis de componentes principales identifica diferentes perfiles de rendimiento en función de las posiciones en partidos internacionales de hockey hierba femenino

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Abstract

The aim of this study was to assess the principal components (PC) of women's field hockey players´ TL distinguishing by playing positions (i.e., back, midfielder, forward). Data were collected from sixteen players belonging to the Spanish National women's field hockey team during 13 official matches from the European Championship, World Series, and Pre-Olympic tournament. The Principal Component Analysis (PCA) grouped a total of 16 variables in five to six PC, explaining between 68.6 and 80% of the total variance. Different variables formed the PC that explain the player's performance in different field positions. There were differences by positions in the distance covered at 21 to 24 km·h^{-1} (midfielders>forwards), decelerations from 5 to 4 m·s^{-2} (midfielders>forwards), and in maximum accelerations (midfielders>backs). Overall, strength and conditioning coaches should combine exercises which induce a high degree of aerobic endurance and power. However, some specification should be made by playing position: (1) defenders should perform training sessions with at least the same amount of volume as in the matches; (2) forwards should perform training efforts that ensure high repeated sprint ability; and (3) midfielders should perform a high training volume to develop high-intensity aerobic endurance, in combination with short-term efforts.

Key words: multivariate data analysis technique, team sport; competition; game-analysis; GPS.

Resumen

El objetivo de este estudio fue evaluar los componentes principales (CP) de rendimiento de las jugadoras de hockey hierba en diferentes posiciones del campo (defensiva, mediocampista, delantera). Se registraron datos de 16 jugadoras de la selección española absoluta de hockey hierba femenino durante 13 partidos oficiales del Campeonato de Europa, Serie Mundial y del Torneo Preolímpico. El Análisis de Componentes Principales (ACP) agrupó un total de 16 variables en cinco/seis CP, lo que explica entre el 68,6 y el 80% de la varianza total. Diferentes variables formaron los PC que explican el rendimiento de las jugadoras en diferentes posiciones del campo. Se encontraron diferencias por posiciones en distancia de 21 a 24 km/h (centrocampistas > delanteras), deceleraciones de 5 a 4 m/s (mediocampistas > delanteras) y en aceleraciones máximas (mediocampistas > defensas). En general, los preparadores físicos deben combinar ejercicios que lleven a un alto grado de resistencia aeróbica y potencia, aunque se deben hacer algunas especificaciones por posición de juego: (1) las defensoras deben realizan sesiones de entrenamiento con al menos la misma cantidad de volumen que en el partido; (2) las delanteras deben realizar durante los entrenamientos esfuerzos que aseguren una alta capacidad de repetir carreras de alta intensidad; y (3) las mediocampistas deben desarrollar una resistencia aeróbica de alta intensidad en combinación con esfuerzos cortos e intensos.

Palabras clave: Técnicas de análisis multivariable; deportes de equipo; competición; análisis del juego; GPS.

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Introduction

Field hockey is an Olympic team sport involving eleven players per team in which players combine aerobic and anaerobic actions in a field measuring 92 x 55 m (Morencos, Casamichana, Torres, Haro, & Rodas, 2019). Just as in other sports, the quantification of both internal and external training load has become in a fundamental part in a practical context to aid game understanding and decision-making regarding training content and prescription (Hodun, Clarke, & Hughes, 2016).

Regarding to the training load management in field hockey, movements are usually categorized according to the playing positions (technical-tactical role) on that they occupy on the playing field (Morencos et al., 2019). Traditionally these have been classified into goalkeeper, defenders, midfielders and forwards (Macutkiewicz & Sunderland, 2011; McGuinness, Malone, Petrakos, & Collins, 2019; Morencos et al., 2019; Vescovi & Frayne, 2015), which is consistent due to the differences found (Gabbett, 2010; Macutkiewicz & Sunderland, 2011; McGuinness, Malone, Petrakos, et al., 2019; Morencos et al., 2019; Vescovi & Frayne, 2015). Macutkiewicz and Sunderland (2011) assessed this factor for the first time and observed that forwards spend more time making high-intensity movements (8% of total time) than midfielders and defenders (6% and 5%, respectively). Despite the changing of rules over the years, this remains consistent. McGuinness, Malone, Petrakos, et al. (2019) found that the defenders were the ones that ran the highest total distances compared to forwards and midfielders (5696 ± 530 m, 5369 ± 578 m, and 5555 ± 456 m, respectively). However, forwards ran a greater relative distance (regarding number of minutes played) than defenders and midfielders (70 - 131 m/min, 79 - 114 m/min, 79 - 129 m/min, respectively). More recently, Morencos et al. (2019) analyzed sixteen elite women players during the European Championship matches. They found that the defenders showed less high-intensity activity (speeds, accelerations, and decelerations) than midfielders and forwards (9.4 ± 2.4%; ES: 0.78 for the midfielders and 33.1 ± 7.2%; ES: 2.1, for the defenders). Therefore, analyses of the demands faced by field hockey players, according to the player's position, provide more useful information to the coaches (Gabbett, 2010; Macutkiewicz & Sunderland, 2011; McGuinness, Malone, Petrakos, et al., 2019; Morencos et al., 2019; Vescovi & Frayne, 2015).

Today, external training load has been analyzed using more than 200 variables regarding the type of movement (e.g., walking, running, sprinting, jumping, tackling), speed (e.g., acceleration, deceleration), direction, and technical tasks characterizing the activity profile as intermittent. In light of the large amount of variable data, it is a challenge to identify those variables which provide the most relevant information about TL (Agras, Ferragut, & Abraldes, 2016) in each training situation. In this way, Principal Component Analysis (PCA) explains the variance of a large set of dependent variables by transforming them into the essential independent original variables (Groth, Hartmann, Klie, & Selbig, 2013; Weaving, Marshall, Earle, Nevill, & Abt, 2014). PCA has been used in ice hockey (Robbins, Renaud, & Pearsall, 2018) and in field hockey (Muazu, 2019), but to date, no study has analyzed PCA according to the field player's position in national team official competitive matches. The aim of this study was to assess the principal components (PC) of women field hockey players´ TL distinguishing by playing positions (i.e., back, midfielder, forward).

Methodology

Participants

Data was collected from eighteen elite international women field hockey players (six backs, six midfielders, six forwards) who participated in the current study (25.7 ± 2.3, years; 165.2±4.9 cm; and, 59.9±5.4 kg). Goalkeepers were excluded from the analysis due to the difference in their roles. Players were selected from the Spanish national squad and were therefore deemed the best players within the training squad. These data arose from the daily player monitoring in which player activities are routinely measured throughout the season. All players were notified of the study's aim and procedures following the Declaration of Helsinki. The ethical committee approved the study of the Camilo José Cela University.

Data collection

The study methodology was written following Rico-González, Los Arcos, Rojas-Valverde, Clemente, & Pino-Ortega (2020) protocol to warrant the strict description of technology use. For the Global Navigation Satellite System (GNSS) to measure distance, 16 points out of 18 were scored, while to measure velocity, 17 points out of 19 were scored. For the description of the methodology for using microelectromechanical systems (MEMS), 17 points out of 20 were described.

Positional data on the field were recorded with a commercial time motion tracking system (WIMU PROTM, Real Track Systems, Almeria, Spain). Each device contains four accelerometers, one gyroscope, one magnetometer, one GNSS, and one Ultra-wideband chip. Additionally, the device allows the register of heart rate (HR) variability through ANT+ technology. For the analysis, the GNSS and inertial measurement sensors were used. This system holds FIFA's both International Match Standard and Quality certificates. Each device consists of an internal microprocessor, 2 GB flash memory, and a high-speed USB interface to record, store, and upload data. The devices are powered by an internal battery with a four-hour life, weigh 70 g in total, and have 81x45x16 mm.

The data were collected using a GNSS sensor, which determines the positioning and location (latitude and longitude) in any part of the world through a constellation of satellites that transmit in specific signal ranges. The data were collected in an open space, in which infrastructure conditions cannot influence data quality, during sunny days and clear sky weather conditions. This study's GNSS device can operate at 10 Hz and is compatible with the Galileo and American satellite constellation, which seems to provide more precision (Jackson, Polglaze, Dawson, King, & Peeling, 2018). The mean number of satellites connected with each device was 12, while the value of DDOP was 0.95. This chip has demonstrated valid and reliable measures (Bastida-Castillo, Gómez-Carmona, Pino-Ortega, & de la Cruz Sánchez, 2019). GNSS/GPS calculates players' position, using a known positioning system (i.e., satellites) as a reference and an object with a new position through RF. The calculation of player position is through trilateration. When the devices were switched on, they were left for 5-minute in the middle of the field to avoid technology lock.

The validity of the inertial measurement unit (IMU; WIMU PROTM, Real Track Systems, Almeria, Spain) was assessed by Bastida-Castillo, Gómez-Carmona, Pino-Ortega, & de la Cruz Sánchez (2017). The devices were attached to the players' upper back in a pocket attached to a tight-fitting garment, placed between the scapulae at the T2-T4 level to avoid unwanted movements. The tight-fitting garment was the same for each player in each game. The calculation of the velocity was made through differential Doppler, and the acceleration was calculated from velocity. Finally, the minimum effort duration and minimum speed for avoiding unrealistic data mentioned were defined by the manufacturer to avoid outliers.

Procedure

The current study was designed to monitor elite women field hockey players during 13 matches (three different competitions in the same year: World Series, European Championship, and Pre-Olympic tournament). A total of 814 data points were analyzed in the whole match. The GPS unit was encased within the confines of a harness and worn by the athletes in each match, and given the use of rolling substitutes, the time each participant spent in match-play was noted as players' "time played". Players' time played was then used to determine players' relative variables during match-play. The data for activity time selections was split in real-time using S VIVO™ software (version 807).

Variables

From a total of 250 variables registered by the IMU devices, Principal Component Analysis (PCA) identified 48 relative variables that were finally analyzed. To compared variables based on playing positions, the following time-related and maximum variables were extracted (Table 1):

Table 1. Variables included in the analysis and each abbreviation.

Abbreviation	**Variable**
Dist; $m \cdot min^{-1}$	Distance covered
$Speed_{Max}$ $km \cdot h^{-1}$	Maximum speed in $km \cdot h^{-1}$
$Distance_{0\text{-}6\ km \cdot h\text{-}1}$	Distance covered from 0 to 6 $km \cdot h^{-1}$
$Distance_{21\text{-}24\ km \cdot h\text{-}1}$	Distance covered from 21 to 24 $km \cdot h^{-1}$
$Distance_{24\text{-}50\ km \cdot h\text{-}1}$	Distance covered at more than 24 $km \cdot h^{-1}$
Peak acceleration	Peak accelerations $km \cdot h^{-1}$
Acc_{Max}	Number of maximum accelerations
Dec_{max}	Number of maximum decelerations
$Acc_{3\text{-}4m \cdot s\text{-}2}$	Number of accelerations per minute from 3 to 4 $m \cdot s^{-2}$
$Acc_{4\text{-}5m \cdot s\text{-}2}$	Number of accelerations per minute from 4 to 5 $m \cdot s^{-2}$
$Dec_{5\text{-}4m \cdot s\text{-}2}$	Number of decelerations per minute from 5 to 4 $m \cdot s^{-2}$
$Dec_{6\text{-}5m \cdot s\text{-}2}$	Number of decelerations per minute from 6 to 5 $m \cdot s^{-2}$
Sprints; $n \cdot min^{-1}$	Number of sprints per minute
Impacts; $n \cdot min^{-1}$	Number of impacts per minute
$Impacts_{8\text{-}100g}$; $n \cdot min^{-1}$	Number of impacts per minute from 8 to 100 g
HR_{Max}	Maximum heart rate
HR_{Avg}	Average heart rate
PL, $au \cdot min^{-1}$	Player Load

Statistical Analysis

A PCA was performed following previously published protocols (Oliva-Lozano, Rojas-Valverde, Gómez-Carmona, Fortes, & Pino-Ortega, 2020; Rojas-Valverde, Sánchez-Ureña, Pino-Ortega, Gómez-Carmona, Gutiérrez-Vargas, Timón, & Olcina, 2019). Factorability of the 48 variables was explored using a correlation matrix, those coefficients $r < 0.7$ between variables were considered for extraction (Hair, Anderson, Tatham, & Black, 1995; Tabachnick & Fidell, 2007). After exclusion of variables with variance= 0, resulted variables (n= 16) were scaled and centered using Z-Scores. PCA suitability was confirmed through Kaiser-Meyer-Olkin adequacy test (KMO= 0.63 [all team], 0.59 [defenders], 0.56 [midfielders] and 0.51 [forwards]) (Hair et al., 1995; Kaiser, 1960) and Bartlett Sphericity test significance ($p < 0.05$) (Bartlett, 1954; Hair et al., 1995). Factor retention was made according to Kaiser's criteria, in consequence, those eigenvalues >1 were considered for each Principal Components (Kim & Mueller, 1978), and a VariMax orthogonal rotation method was used to identify high correlations between components to offer different information (Thompson, 2004). Those PC loadings >0.7 were considered for extraction (Hair et al., 1995), and when a cross-loading was found between PCs, only the highest factor loading was retained (Kaiser, 1960).

Differences between player's positions were explored using a one-way analysis of variance, and Post-Hoc of Bonferroni was performed to examine specific differences in those variables found in PCA. Omega squared ($\omega p2$) was selected to analyze the magnitude of the differences, and it was classified as follows: <0.01 trivial; >0.01 small; >0.06 moderate and >0.14 large (Cohen, 1988). Alpha was set at $p < 0.05$, and all data was analyzed and systematized using the e Statistical Package for the Social Sciences (SPSS, IBM, SPSS Statistics, v.22.0 Chicago, IL, USA).

Results

From PCA of the whole team, there were five PC's extracted explaining a total of 68.6% of the variance; in backs, six PC's represented 80% of the variance. Six PCs denoted 79.2% in midfielders, and forwards in six PCs implied 77.7% of the variance. Fourteen variables were extracted in the whole team and forwards, sixteen in backs, and thirteen in midfielders.

Most of the whole team and midfielder's variance was explained by PC1 (23.7-27.8% respectively) considering high-intensity related variables for midfielders as $\text{Distance}_{21\text{-}24 km \cdot h^{-1}}$, $\text{Distance}_{24\text{-}50 km \cdot h^{-1}}$, $\text{Acceleration}_{3\text{-}4 m \cdot s^{-2}}$, and Speed_{Max}. PC1 in backs was explained in 25.9% by Distance, $\text{Distance}_{0\text{-}6 km \cdot h^{-1}}$, Sprints, PL and $\text{Impacts}_{8\text{-}100g}$, variables. And finally, PC1 explained 23.3% of total variance for forwards through internal and external load variables as Heart Rate_{avg}, Heart Rate_{max}, and $\text{Acceleration}_{3\text{-}4 m \cdot s^{-2}}$ (see figure 1).

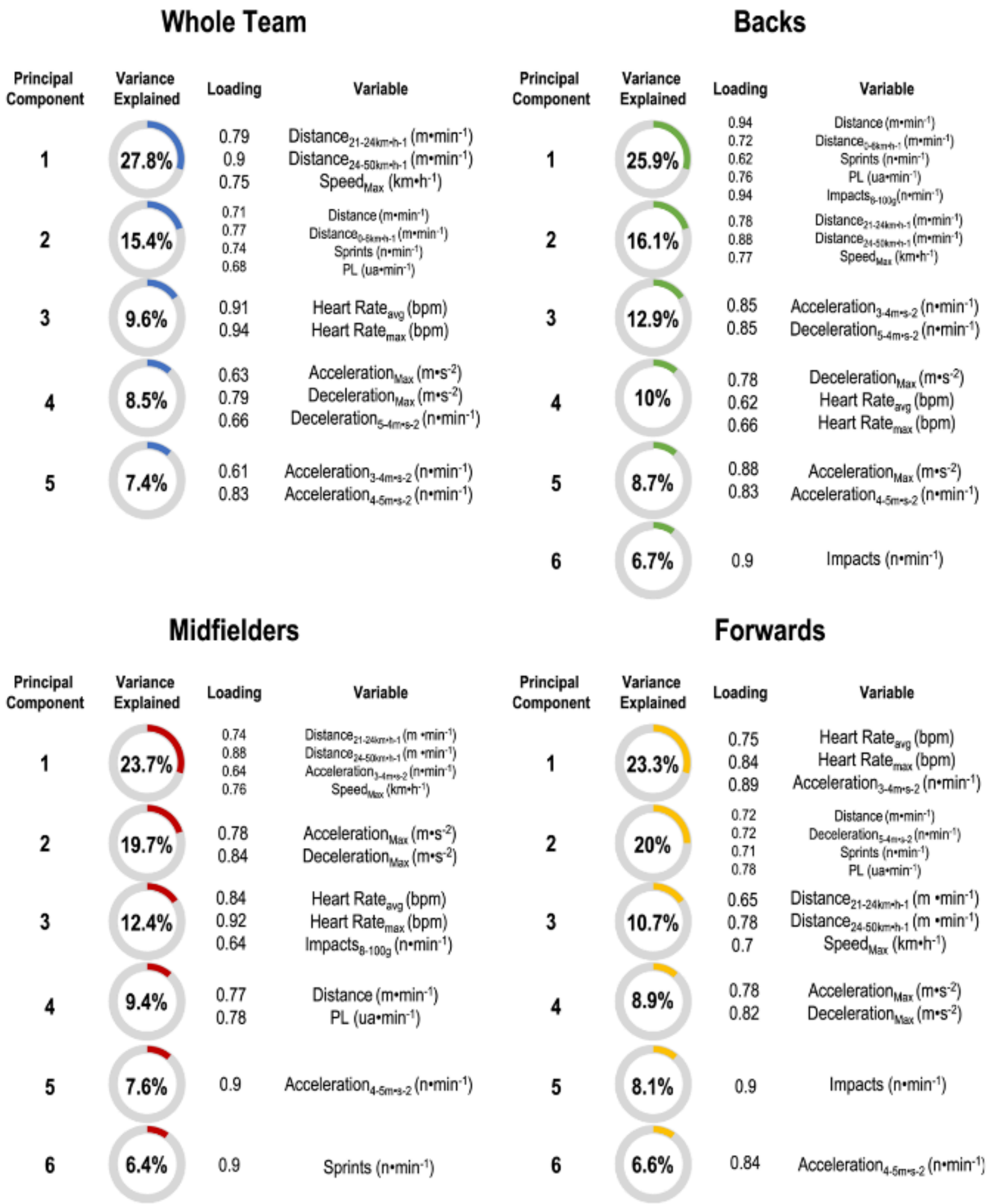

Figure 1. Principal component analysis of external and internal load in elite women field hockey players by position.

Analysis of variance by player position suggested statistical differences in Distance$_{21\text{-}24km•h\text{-}1}$ and Deceleration$_{5\text{-}4m·s\text{-}2}$ between midfielders>forwards (F= 7.36, p= 0.32, ω_p^2= and F= 9.55, p= 0.02, ω_p^2= respectively) and in Accelerations$_{Max}$ between midfielders>backs (F= 8.66, p= 0.24, ω_p^2=) (see figure 2).

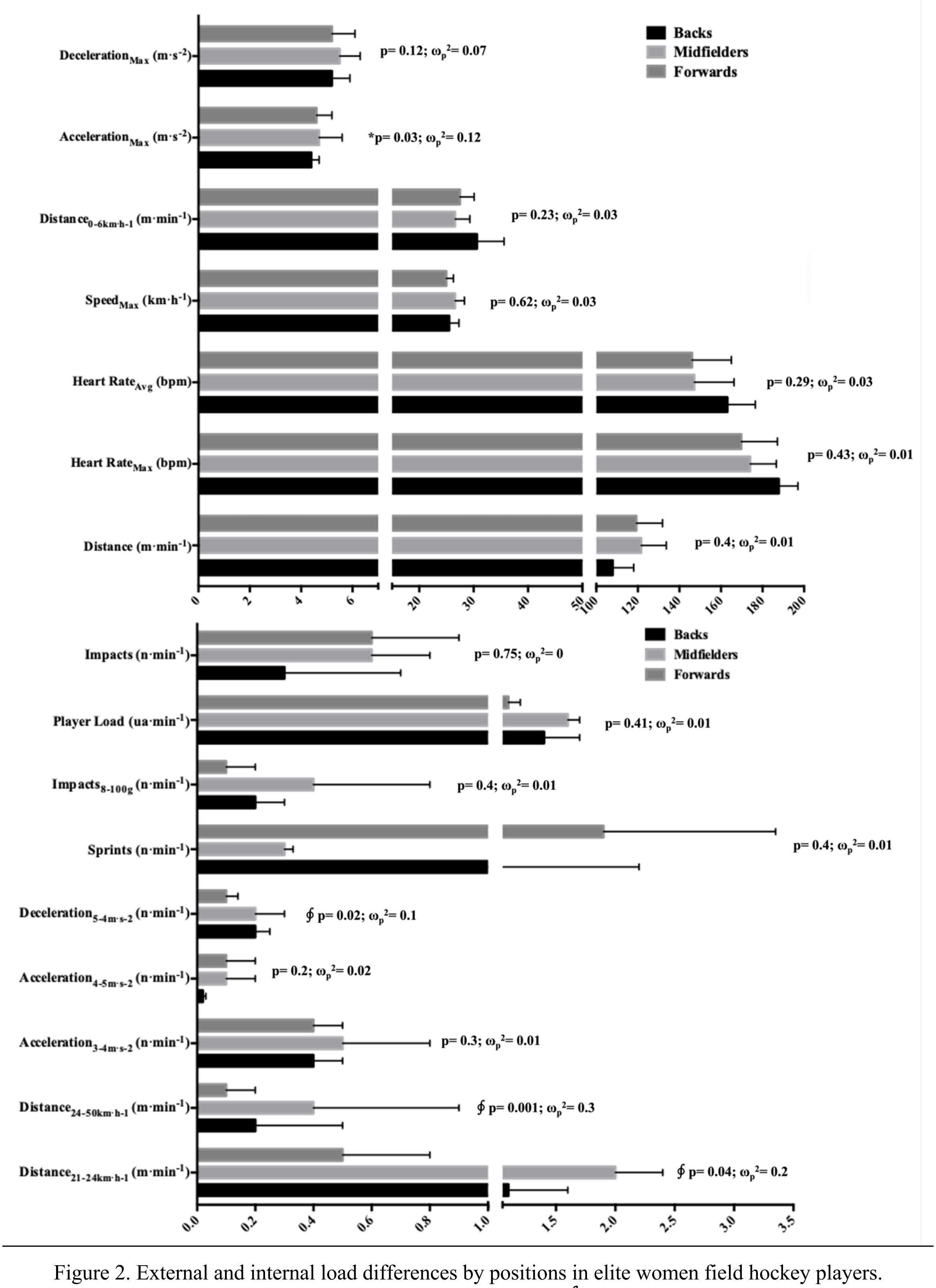

Figure 2. External and internal load differences by positions in elite women field hockey players. Statistical differences between * midfielders and backs and ∮ between midfielders and forwards.

Discussion

The aim of this study was to assess the principal components (PC) of women field hockey players´ TL distinguishing by playing positions (i.e., back, midfielder, forward). The main findings were: (1) different variables formed the PC of back, midfielder and forward international field hockey players, and the team as a whole; (2) analysis of variance by player position suggested statistical differences among backs, midfielders and forwards.

Different PC were extracted from different player positions (i.e., backs, midfielders, and forwards) and the whole team. Five PC explained 68.7% of the entire team's performance. In comparison, six variables explained 80.3%, 79.2%, and 76.6% of each field position player's performance for backs, midfielders, and forwards, respectively. These results are based on different international players´ performance between a team as a whole and each player based on their field position (Delves, Bahnisch, Ball, & Duthie, 2019; McGuinness, Malone, Hughes, Collins, & Passmore, 2019; McGuinness, Malone, Petrakos, et al., 2019; Morencos et al., 2019; Romero-Moraleda, Morencos, Torres, & Casamichana, 2020). Hence, overall suggestions highlight that strength and conditioning specialists should design training tasks in which a high degree of aerobic endurance is combined with considerable strength and power to perform high-intensity short-term efforts such as accelerations and decelerations. However, since differences have been found among players from different field positions, the analysis of a team could report misinformation. Therefore, international women´s field hockey teams' strength and conditioning coaches should perform an individualized training prescription to ensure optimal physical fitness and conditioning for each player.

The most representative variables for backs were: Distance, Distance from 0 to 6 $km \cdot h^{-1}$, Sprints, PL and Impacts from 8 to 100 g; for midfielders: Distance from 21 to 24 $km \cdot h^{-1}$, Distance from 24 to 50 $km \cdot h^{-1}$, Acceleration from 3 to 4 $m \cdot s^{-2}$, and maximum speed; and for forwards: average heart rate, maximum heart rate, and Acceleration from 3 to 4 $m \cdot s^{-2}$. Specifically, low-intensity variables such as Distance and Distance 0-6 km/h were found in PC1 for backs. This is consistent with those studies that showed that backs usually accumulate more minutes than midfielders and forward players (Morencos et al., 2019). Therefore, strength and conditioning coaches should ensure that backs perform efforts during, at least, a similar number of minutes as in the matches. Besides, sprints, PL, and Impacts from 8 to 100 g observed in PC1 may also be related to this lower speed with the potential for more accelerations and decelerations, and the technical interceptions needed in their defensive role (Delves et al., 2019). In combination with training volume, strength and conditioning specialists should ensure that defenders engage in high intensity running and short-term efforts such as impacts, accelerations, decelerations, and impacts.

Regarding forwards´ performance, PC were formed by heart rate (average and maximum), accelerations (at different intensities and maximum), the distance covered at different intensities, decelerations, sprint, TL, maximum speed, and impacts. This is consistent with Lythe and Kilding (2011), who highlighted that forwards need to perform accelerations/decelerations quickly and carry out high-speed actions as they react to the presence of the ball to manufacture goal-scoring opportunities, in turn creating greater free-running opportunities (Lythe & Kilding, 2011). These repeated bouts of high-intensity effort seeking scoring opportunities, regardless of whether they get the ball or not, may be related to the HR weight as a representative variable as they spend the most time between < 69 – 84 % HRmax (McGuinness, Malone, Petrakos, et al., 2019). Therefore, strength and conditioning coaches should design training tasks based on repeated sprint ability to ensure greater goal-scoring opportunities with more time free from opposing players.

Finally, midfielders' 6 performance PC were formed by distances at different intensities, accelerations (at different intensities and maximum), speed, decelerations, heart rate (average and maximum), impacts, and sprints. Specifically, distance covered at high speed formed the first PC for midfielders. It is consistent because they are the middle point of a network, acting as a link between the defenders and the forwards which gives them space to increase their moderate - high-intensity distances (Hodun et al., 2016). Due to their positional roles, midfielders covered more distance at high-intensity than backs (Lythe & Kilding, 2011). These players are exposed to many opportunities that allow them to move at high speed. Also, because of positional spacing and the midfield position's nomadic nature, players are able to achieve high relative distances across different duration epochs, and they can accumulate higher accelerations (McGuinness, Malone, Petrakos, et al., 2019). As a practical application, midfielders should perform a large volume of high-intensity efforts during training, combined with accelerations and decelerations.

In accordance with the differences obtained and discussed above on the PCA results and previous literature, positional variations during competitive match-play exist (McGuinness, Malone, Petrakos, et al., 2019). When these variables are compared among positions, midfielders show significantly higher values for Distance from 21 to 24 km·h-1, Deceleration from 5 to 4 m·s-2, and maximum accelerations than the other players. According to McGuiness, Malone, Petrakos, et al., (2019) midfielders have been reported to show higher "worst-case scenarios". However, are technical-tactical aspects that differentiate each playing position, creating different behaviors as a function of their particular roles (Delves et al., 2019; Vescovi & Frayne, 2015).

The current investigation presents some limitations. First, a lack of inclusion of additional variables of the game formats studied in the analysis (e.g., result, rival, rotations, etc.) is one of the limitations of the present study. Secondly, as this research considers 13 international games from the same team, further studies should perform PCA analyzing more matches and more teams.

Practical applications

The PCA may be used in two ways: decision making - training design, and training assessment from the variables that report the most relevant information for training prescription. Hence, two main practical applications can be highlighted from the results found:

- From the combination of the main variables for each playing position, strength and conditioning coaches should design those training tasks considering that a high degree of endurance efforts and strength and power elicit from the players to carry out specific actions like accelerating and decelerating. Specifically, strength and conditioning coaches should ensure: (1) defenders to perform training sessions with, at least, the same amount of volume as in the matches; (2) forwards to perform those training efforts that ensure high repeated sprint ability; and (3) midfielders should perform a high training volume to develop high-intensity aerobic endurance, in combination with shorth terms efforts.

- The assessment of international women field hockey players' performance may be done through the following variables: distances at different intensities (i.e., from 21 to 24 $km \cdot h^{-1}$and from 24 to 50 $km \cdot h^{-1}$), maximum speed, sprint, PL, heart rate (max and mean), accelerations, and decelerations. However, since different PC were found in different playing positions, the players' load assessment should be done, at least, by playing position. Specifically:
    - Defenders: distances at different intensities, sprint, PL, impacts, speed, accelerations at different intensities, maximum decelerations, heart rate (average and max), and impacts.
    - Forwards: heart rate (average and maximum), accelerations (at different intensities and maximum), the distance at different intensities, decelerations, sprint, TL, maximum speed, and impacts.
    - Midfielders: distances at different intensities, accelerations (at different intensities and maximum), speed, decelerations, heart rate (average and maximum), impacts, and sprints formed the 6 PC.

Conclusions

The quantification of competition matches' demands is often useful in a practical context. Since external/internal training load has been analyzed with more than 200 variables, a challenge lies in identifying those variables that provide the most relevant TL information. In this sense, strength and conditioning coaches should consider the PCA to quantify match and training load through the most relevant variables across different playing positions.

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