Optimal relative workload for managing low-injury risk in lower extremities of female field hockey players
A retrospective observational study

Taegyu Kim, ATC, PhD[a], Jong-Chul Park, PhD[a,b], Jae-Myoung Park, PhD[c], Hokyung Choi, PT, PhD[d,*] [iD]

Abstract

Our study aimed to investigate the relative workload that is related to the injury in lower extremities of female field hockey players and to identify the optimal ratio of acute to chronic workloads (ACWR) depending on the playing position to manage low risk of sports-related injuries.

Data were collected using a global positioning systems unit on a full-time basis and during competition among 52 players who were enrolled in Korea National Team. The ACWR was calculated by dividing the most recent 1 week workload by the prior 4 weeks workload. Injury risk was calculated for each category from very low to very high based on a z-score.

In striker and midfielder, the injury risk was the lowest in the moderate-low category of total distance covered, meters per minute (MpM), repeated high-intensity effort bouts, and acceleration bouts, and the moderate-high category of high-intensity running distance (HID). The injury risk of a defender was the lowest in the moderate-low category of HID and MpM.

The ACWR in total distance covered, MpM, repeated high-intensity effort bouts, and acceleration bouts should stay within the moderate-low category in striker and midfielder positions and HID and MpM in defender positions in order to manage low-risk of non-contact and soft tissue injuries in female field hockey players.

Abbreviations: ACC = acceleration bouts, ACWR = ratio of acute to chronic workloads, AEs = athlete exposures, CI = confidence intervals, DEC = deceleration bouts, DF = defender, GPS = global positioning systems, HID = high-intensity running distance, MF = midfielder, MpM = meters per minute, RHIE = repeated high-intensity effort bouts, ST = striker, TD = total distance covered.

Keywords: low-risk, playing position, ratio of acute to chronic workloads, sports-related injury

1. Introduction

Athletes and their support staff use training and competition workloads for stimulating homeostatic responses and biological adaptation of the human body's systems.[1] This leads to

improvement in fitness and performance.[1] With regard to the general adaptation syndrome, training and competition workloads below the optimum are insufficient to produce adaptation.[2] Therefore, many athletes push their training workloads, that is, a product of training intensity, volume, and frequency, to the limits in order to maximize their performance improvement.[1] However, training and competition workloads above the optimum may lead to overtraining that is largely associated with a higher incidence of sports-related injuries.[3] A previous study mentioned that collision sports athletes whose training exceeded their workload threshold were 70 times more likely to sustain non-contact soft tissue injury,[4] another study also showed that elite rugby league players had 2.7 times higher of the injury risk when they ran at over 7 m s^{-1}.[3]

A workload-injury etiology model updated by Windt and Gabbett[5] explained that training and competition workloads contribute to injury risk by exposing athletes to potentially injurious situations, while they have a positive effects on numerous modifiable internal risk factors. This means that total cumulative or absolute workloads are not always associated with increased injury risk, and high workloads may contribute to well-developed various physical qualities, which is reducing injury risk.[5–7] Many researchers mentioned that the rate of change in workloads over time, that is, relative workload, is a strong predictor.[5,6,8] The ratio of acute workload for 1 week (that means fatigue) to chronic workload for 3 to 6 weeks (that means fitness) is considered a best practice approach to monitor athlete workloads.[6]

Table 1

Participants' characteristics.

Group	Position			Age (yrs)	Height (cm)	Weight (kg)	Career (yrs)
	ST	MF	DF				
Injured (n = 28)	8 (28.6)	11 (39.3)	9 (32.1)	28.07 ± 2.94	165.17 ± 4.32	59.35 ± 5.46	15.14 ± 3.35
Non-injured (n = 24)	10 (41.7)	10 (41.7)	4 (16.6)	24.33 ± 3.01	164.54 ± 3.81	59.12 ± 3.49	11.16 ± 3.48

Values: frequency/percentage and mean ± standard deviation.
DF = defender, MF = midfielder, ST = striker.

Many previous studies have shown that the change rate or spikes in workloads were strongly associated with sports-related injuries.[8–10] Professional rugby union players who had large week-to-week changes (1069 arbitrary units) in training workloads had an increased risk of injury (odds ratio: 1.68) as well as a high 1-week cumulative workload (1245 arbitrary units).[9] Also, cricket fast bowlers with a large increase (200%) in 1-week workload compared with chronic workload, had an increased injury risk (relative injury risks: 3.3),[8] and Australian football players who experienced an approximate 75% change in previous to current week workload were 2.58 times more likely to be injured than those who experienced an approximate 15% change.[10] Therefore, adequate rates of change in workloads are necessary for athletes' fitness and performance improvement through adaptation and skill acquisition without sports-related injury.[5]

Studies in field hockey have increased through the development of motion analysis software and global positioning systems (GPS).[11] International female field hockey players cover a total distance of 5541 m, of which 232 m are at over $19\,km\,h^{-1}$.[11,12] Likewise, field hockey is one of the fastest team sports such as football, rugby, or others, and many female players suffer from 0.7 injuries per match, equaling 23.4 to 44.2 injuries per 1000 player match hours.[13] Injuries to the lower extremities are especially common, accounting for over 50% of the total injuries during training or competition.[14,15] These injuries occur during training or competition and negatively influence the success of individual players and/or the entire team.[16]

Over a 1.5 in ratio of acute to chronic workloads (ACWR) has been associated with large increases in injury risk.[6,16] A players' ACWR should be kept at a range of 0.85 to 1.35.[16] However, this range is suitable for players in cricket, rugby, or Australian football. Therefore, information on adequate workloads are required for female hockey players who have relatively frequent changes in workload. Also, playing a position that effects the activity profile of the player may also need to be considered.[11] The aim of our study was to investigate the relative workload via a GPS unit that was related to non-contact and soft-tissue injuries in the lower extremities of elite female field hockey players. We also aimed to identify the range of an optimal ACWR depending on the playing position in order to manage low-risk of sports-related injuries. We hypothesized the following: specific GPS variables would be related to the occurrence of non-contact injury in lower extremities depending on their playing position, the injury risk differed across categories of ACWR in each GPS variable.

2. Materials and methods

2.1. Study design

This study was a retrospective observational study of elite female field hockey players competing at the highest level of competition in field hockey. Data were collected from elite female field hockey players who were enrolled in the Korea National Team and trained on a full-time basis and played in the competition from January 2015 to December 2018.

2.2. Participants

A total of 52 elite female hockey players had no pain in their lower extremities or lower back within the 3 months preceding data collection, and they were analyzed according to their primary positions for a given match. Three positional groups were identified[11]; striker (ST), midfielder (MF), and defender (DF; Table 1). Goalkeepers were excluded from the study due to the different nature of their activity.[17] Written informed consent was obtained from all participants and ethical approval was obtained from the Research Ethics Committee of Korea National Sport University.

2.3. Quantifying workload

Workload was quantified using GPS units (GPSports, SPI-HPU 15 Hz, Canberra, Australia), with data collected from game-based training and matches. Approximately 15 minutes before the warm-up period, subjects were pre-fitted with an appropriately sized-vest housing the portable GPS unit at the T2 to T6 level of the spinal column. Following each training or match, the data were downloaded using a specialized analysis software (Team AMS, GPSports, Canberra, Australia).

The workload variables via GPS unit were as follows: total distance covered (TD) included walking, jogging, fast running, and sprinting; high-intensity running distance (HID) described as TD at $>15.1\,km\,h^{-1}$[3]; meters per minute (MpM) represented the TD per minute[18]; repeated high-intensity effort bouts (RHIE) signified frequency of efforts at $>15.1\,km\,h^{-1}$[18]; maximal velocity; acceleration (ACC) and deceleration (DEC) bouts represented frequency of maximal acceleration ($\geq 2.78\,m\,s^{-2}$ and $\leq -2.78\,m\,s^{-2}$, respectively).[19]

2.4. Definition of injury

All injuries that occurred during training or matches were recorded for each event by well-trained medical practitioners who were enrolled in the Korea National Team. Injury information was classified by injury type (description), body site (injury location), and mechanism (non-contact or contact) and updated on the injury recording sheet. For the purpose of this study, an injury was defined as any non-contact, soft-tissue injury in lower extremities.

2.5. Data reduction

All individual players' workload data via GPS were categorized in weekly blocks and averaged for 1 and 4 weeks leading up to an

The difference of ratios of acute to chronic workload (ACWR) between injury block, pre-injury block, and total average in injured striker.

Sub-variables	Injury block[a]	Pre-injury block[b]	Total average[c]	F (P)	Post hoc
Total distance covered	1.15 ± 0.17	1.06 ± 0.12	1.01 ± 0.06	9.086 (.002)	a > b,c
High intensity distance	1.16 ± 0.19	1.02 ± 0.21	1.01 ± 0.07	4.704 (.021)	a > b,c
Meters per minute	1.13 ± 0.19	1.03 ± 0.10	1.00 ± 0.05	5.128 (.016)	a > c
Repeated high-intensity effort bouts	1.18 ± 0.23	1.06 ± 0.22	0.99 ± 0.09	4.666 (.022)	a > c
Maximal velocity	1.01 ± 0.05	0.99 ± 0.04	0.99 ± 0.01	0.585 (.567)	−
Acceleration bouts	1.26 ± 0.23	1.15 ± 0.23	1.01 ± 0.09	6.851 (.005)	a > c
Deceleration bouts	1.08 ± 0.26	1.11 ± 0.18	0.98 ± 0.08	1.805 (.190)	−

injury (injury block), averaging values across 1 and 4 weeks before the injury block (pre-injury block) as well as averaging values from the beginning of the data collection to the point of injury (total average).[20] One-week load and 4-week rolling averages represented acute workloads and chronic workloads, respectively. The ACWR was calculated by dividing the acute workload by the chronic workload.[8] Injured participants' ratios of injury block were compared to those of the pre-injury block and the total average. Also, all participants' ratios were classified into discrete ranges from very low through very high based on z-scores.[16,17,21] Subsequently, the injury risk was calculated for each range.

2.6. Statistical analyses

The incidence rate of injuries was calculated from the number of injuries per 100 athlete exposures (AEs) which represents 1 athlete participating in 100 training/competitions. A significant difference of ratios between injury and pre-injury blocks as well as injury blocks and total averages was assessed using repeated-measure analysis of variance with a least significant difference test. Based on these significant results, injury risks were calculated as the number of injuries sustained relative to the number of exposures to each workload classification using z-scores.[16,17] A level of significance was set at 0.05 for all hypothesis testing.

3. Results

Through the data collection period, 28 players suffered 38 injures, indicating that an incidence rate was 6.58 injuries per 100AEs (95% confidence intervals [CI]: 4.49–8.67 injuries per 100AEs). Eight STs were injured in their lower extremities, which indicated 6.39 injuries per 100AEs (95%CI: 4.49–8.67 injuries per 100AEs), 11 MFs and 9 DFs sustained 7.08 injuries (95%CI: 3.71–10.4 injuries per 100AEs) and 6.06 injuries (95%CI: 2.30–9.81 injuries per 100AEs) per 100AEs, respectively.

In the ST position, injured players had a higher ratio of TD (P = .002), HID (P = .021), MpM (P = .016), RHIE (P = .022), and ACC (P = .005) in the injury block compared to the pre-injury block and/or total average (Table 2). The injury risk was the lowest in the moderate-low category of TD (ranging from 0.94–1.07), MpM (ranging from 0.93–1.07), RHIE (ranging from 0.93–1.10), and ACC (ranging from 0.92–1.12), and the moderate-high category of HID (ranging from 1.16–1.34), as shown in Figure 1.

Injured MFs also had a higher ratio of TD (P = .004), HID (P = .036), MpM (P = .020), RHIE (P = .013), ACC (P = .005), and DEC (P = .007) in the injury block compared to the pre-injury block and/or total average (Table 3). The injury risk was lowest in the moderate-low category of TD (ranging from 0.92–1.12), MpM (ranging from 0.95–1.07), RHIE (ranging from 0.95–
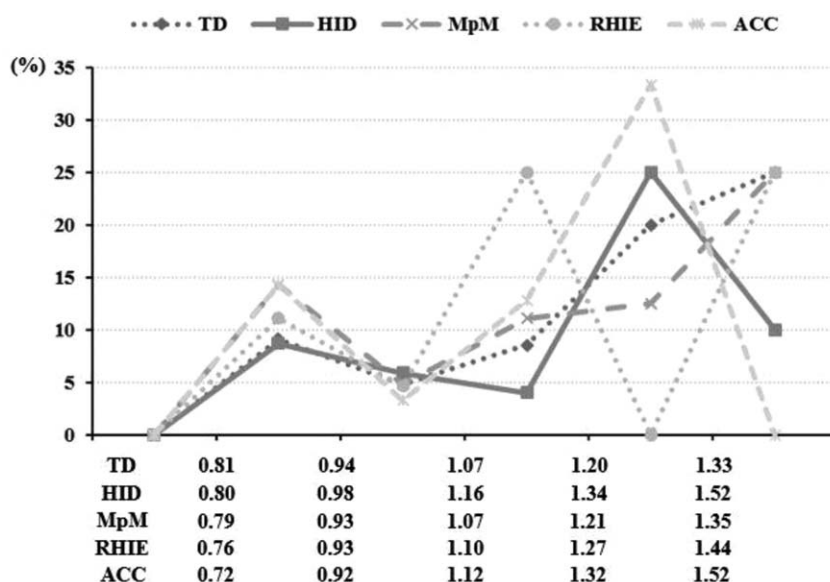

Figure 1. Injury risk in discrete ranges of a ratio of acute to chronic workload for striker. ACC = acceleration bouts, HID = high-intensity running distance, MpM = meters per minute, RHIE = repeated high-intensity effort bouts, TD = total distance covered.

Table 3

The difference of ACWR between injury block, pre-injury block, and total average in injured midfielder.

Sub-variables	Injury block[a]	Pre-injury block[b]	Total average[c]	F (P)	Post hoc
Total distance covered	1.11±0.13	1.04±0.12	0.99±0.03	6.580 (.004)	a>c
High intensity distance	1.15±0.16	1.03±0.26	1.01±0.05	3.691 (.036)	a>c
Meters per minute	1.10±0.15	1.03±0.15	0.99±0.03	4.432 (.020)	a>c
Repeated high-intensity effort bouts	1.17±0.18	1.07±0.24	1.00±0.05	4.983 (.013)	a>c
Maximal velocity	1.00±0.04	0.99±0.03	1.00±0.01	0.358 (.702)	−
Acceleration bouts	1.26±0.35	1.02±0.21	1.02±0.08	6.185 (.005)	a>b,c
Deceleration bouts	1.18±0.28	1.13±0.20	1.00±0.05	5.912 (.007)	a,b>c

ACWR = ratio of acute to chronic workloads.

1.10), ACC (ranging from 0.87–1.16), and DEC (ranging from 0.88–1.10). The moderate-high category of HID (ranged from 1.13–1.31), as shown in Figure 2.

In the DF position, injured players had a higher ratio of HID ($P=.009$), MpM ($P=.040$), and RHIE ($P=.015$) in the injury block compared to the pre-injury block and/or total average (Table 4). The injury risk was the lowest in the moderate-low category of HID (ranging from 0.97–1.02) and MpM (ranging from 0.97–1.05). The risk was the highest in the high category of RHIE (ranging from 1.37–1.58), as shown in Figure 3.

4. Discussion

This study investigated the relationship between workload via GPS unit and non-contact and soft-tissue injuries in lower extremities of elite female field hockey players, depending on their playing position. In ST and MF, the injury risk was the lowest in the moderate-low category of TD (ranging from 0.94–1.07 and 0.92–1.12, respectively), MpM (ranging from 0.93–1.07 and 0.95–1.07, respectively), RHIE (ranging from 0.93–1.10 and 0.95–1.10, respectively), and ACC (ranging from 0.92–1.12 and 0.87–1.16, respectively) bouts, and the

moderate-high category of HID (ranging from 1.16–1.34, and 1.13–1.31 respectively). The injury risk of the DF was the lowest in the moderate-low category of HID (ranging from 0.97–1.02) and MpM (ranging from 0.97–1.05), while the risk was the highest in the high category (ranging from 1.37–1.58) of RHIE.

Field hockey has a higher rate of injuries compared to other sports as it is played with a hard, fast-moving projectile and a stick.[13,22] A study conducted at the Rio Olympic Games in 2016 demonstrated that above 10% of all field hockey players were injured and approximately 30% of injured players missed training or competitions due to their injuries.[1] For female field hockey players, a rate from 2008 to 2009 through 2013 to 2014 was 3.25 injuries and 1.73 injuries per 1000AEs in college and high school, respectively.[22] The number of injuries per 1000 player match hours was 29.1 injuries in women and 48.3 injuries in men.[13] Our study illustrated that the incidence was 6.58 injuries per 100AEs and ranged from 6.60 to 7.08 injuries per 100AEs. This was higher than the results of previous studies. Our study calculated the rate of injuries by including only game-based training and competitions in which data were collected via GPS, resulting in these differences. For more valid estimates of sports
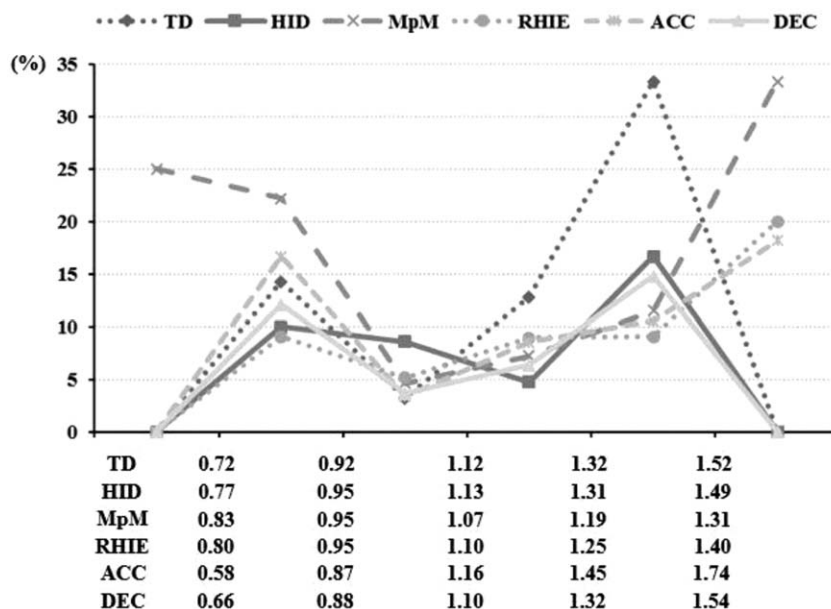

Figure 2. Injury risk in discrete ranges of a ratio of acute to chronic workload for midfielder. ACC = acceleration bouts, DEC = deceleration bouts, HID = high-intensity running distance, MpM = meters per minute, RHIE = repeated high-intensity effort bouts, TD = total distance covered.

Table 4

The difference of ACWR between injury block, pre-injury block, and total average in injured defender.

Sub-variables	Injury block[a]	Pre-injury block[b]	Total average[c]	F (P)	Post hoc
Total distance covered	1.04±0.09	1.00±0.15	0.99±0.03	0.781 (.473)	–
High intensity distance	1.31±0.22	1.00±0.33	0.97±0.05	6.274 (.009)	a>b,c
Meters per minute	1.08±0.09	0.98±0.15	0.99±0.02	3.857 (.040)	a>c
Repeated high-intensity effort bouts	1.25±0.24	1.05±0.26	0.97±0.04	5.312 (.015)	a>b,c
Maximal velocity	1.00±0.05	0.99±0.03	0.99±0.01	0.227 (.799)	–
Acceleration bouts	1.20±0.44	1.16±0.49	0.99±0.06	0.736 (.493)	–
Deceleration bouts	1.17±0.21	1.13±0.50	0.99±0.06	0.751 (.486)	–

ACWR = ratio of acute to chronic workloads.

injury incidences in female field hockey, systematic surveillance platforms would be required in order to collect data.

The increased workloads result in higher levels of neuromuscular fatigue, subsequently precipitating injury while performing a cutting maneuver.[5] The exposures to a spike in external workload, that is, a high ACWR, especially increases the risk for non-contact injuries.[16] In elite football players competing in European leagues, injury incidence was higher when the internal workload (i.e., rate of perceived exertion) ratio was below 0.85 (relative risk=1.31) and above 1.25 (relative risk=1.37).[23] English premier league footballer players had the greatest non-contact injury risk when their external workload (i.e., TD, low-intensity distance in meters, and number of accelerations and decelerations) ratios were above 2.0 (relative risk=3.7–3.9).[24] Our study demonstrated that the moderate-low range of TD (ranging from 0.94–1.07), MpM (ranging from 0.93–1.07), RHIE (ranging from 0.93–1.10), and ACC (ranging from 0.92–1.12) in ST and MF positions had a lower injury risk than other ranges. DFs also had the lowest injury risk in the moderate-low range of HID (ranging from 0.97–1.02) and MpM (ranging from 0.97–1.05). These results support the recent literature of sports science that stated a spike in workload, that is, a higher ACWR, contributed to non-contact injury risk in elite athletes.[16,17,25] Therefore, workload ratio must be consistently monitored in order to manage low-risk of non-contact soft tissue injuries in the lower extremities. Also, residual fatigue that players experience,

that is defined as internal workload, can have a strong influence on injury rates.[20] A ratio of acute to chronic internal workload should be monitored.

Distances covered at high intensities are strongly related to physical performance or training status in team sports events, for example, soccer.[26] However, greater amounts of HID resulted in additional soft tissue injuries in lower extremities.[3] Especially, HID is the predominant injury mechanism of hamstring strain injuries.[27] In our study, injured hockey players had a higher ACWR of HID and RHIE. However, the high-intensity distance of injured soccer players showed no significant difference between injury blocks and pre-injury blocks or season average.[20] A previous study mentioned that the total HID performed over 4 weeks, not a spike in HID, influenced the hamstring strain injury risk,[28] and decreased HID in the prior week reduced the risk of hamstring strain injury.[28] This is related to the results of our study in which the ST and midfield positions had the lowest injury risk in the moderate-high range of HID, unlike RHIE. However, the DF position had the lowest in the moderate-low range. Further studies are required to suggest new methods of data reduction for HID, that is, percentage of TD, depending on the players' physiological characteristics and playing position.

In recent years, GPS tracking devices have been widely used to analyze the movement patterns of players during training or competition in order to quantify the physical demands of team sports events,[26] and to identify the correlation of sports injuries
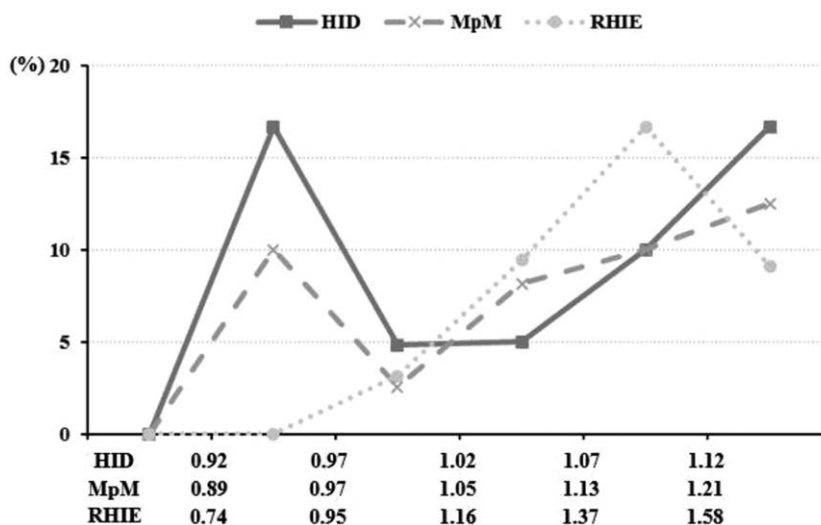
Figure 3. Injury risk in discrete ranges of a ratio of acute to chronic workload for defender. HID = high-intensity running distance, MpM = meters per minute, RHIE = repeated high-intensity effort bouts.

and GPS variables.[3,14] Although the etiology of injury is complex, dynamic, multifactorial, and context dependent,[5] a high chronic workload assists in developing positive physiological adaptations, resulting in players' potential preventative effects.[5,6] Therefore, our study was also conducted to disseminate useful information regarding the setting of an optimal training workload by verifying the GPS variables related to sports injuries for elite female field hockey players. However, as recent studies have mentioned, the recovery status as well as the workload may be related to sports injuries,[25] further studies are required in order to manage both the workload and the recovery status to minimize the odds of injuries.

This study has found the variables via GPS unit that was related to non-contact and soft-tissue injury in the lower extremities and the optimal range of ACWR depending on the playing position in order to manage low-risk of sports-related injuries for female field hockey players. This information may be practical for medical and conditioning staffs when workload volume might be determined objectively for individual players. But, for other skill-level female field hockey team and other team sports, these results should be applied carefully because movement demands are specific to both player's skill-level and sport event.[10]

5. Conclusions

This study illustrated that the ACWR in TD, MpM, RHIE, and ACC should stay within the moderate-low category in ST and MF positions and HID and MpM in DF positions in order to manage low-risk of non-contact and soft tissue injuries in female field hockey players. These results provide an affordable information to prevent sports-related injuries, however many questions remain and further research is required to investigate whether both workload and recovery status have a relationship regarding the odds of injuries in elite female field hockey players.

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Author contributions

Conceptualization: Taegyu Kim.
Data curation: Jong-Chul Park, Jae-Myoung Park, Hokyung Choi.
Formal analysis: Taegyu Kim, Hokyung Choi.
Methodology: Jong-Chul Park, Jae-Myoung Park, Hokyung Choi.
Supervision: Taegyu Kim.
Writing – original draft: Taegyu Kim, Jae-Myoung Park, Hokyung Choi.

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