2-2019

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Digital Object Identifier (DOI)
https://doi.org/10.26603/ijspt20190088

IJSPT

ORIGINAL RESEARCH

VOLLEYBALL OVERHEAD SWING VOLUME AND INJURY FREQUENCY OVER THE COURSE OF A SEASON

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ABSTRACT

Background: Overuse injuries are common in volleyball; however, few studies exist that quantify the workload of a volleyball athlete in a season. The relationship between workload and shoulder injury has not been extensively studied in women's collegiate volleyball athletes.

Hypothesis/Purpose: This study aims to quantify shoulder workloads by counting overhead swings during practice and matches. The purpose of the current study is to provide a complete depiction of typical overhead swings, serves, and hits, which occur in both practices and matches. The primary hypothesis was that significantly more swings will occur in practices compared to matches. The secondary hypothesis was that greater swing volume and greater musculoskeletal injury frequency will occur in the pre-season than during the season.

Study Design: Prospective cohort

Methods: Researchers observed practice and match videos and counted overhead serves and attacks of 19 women's collegiate volleyball players for two seasons. Serves, overhead hits, and total swings (serves + hits) were the dependent variables; event (matches and practice) along with position (defensive specialists, setter, outside hitter, and middle blocker) were the independent variables. Musculoskeletal injury frequency and swing volume workload were compared across pre-season and competitive season time periods.

Results: Across all positions except outside hitters twice as many total swings occurred in practices compared to matches ($p = .002$) resulting in an average of 19 (CI_{95} 16.5, 21.5) more swings in practice than in matches. The average number of total swings during the pre-season 47.1 (CI_{95} 44.1, 50.1) was significantly greater than average swings per session during the competitive season 37.7 (CI_{95} 36.4, 38.9) ($p < 0.001$) resulting in a mean difference of 9.4 (CI_{95} 6.1, 12.7) swings. The number of athletes limited in participation or out due to a musculoskeletal injury during the pre-season (2.9%) was greater than during the season (1.1%) ($p = 0.042$).

Conclusion: These findings support the primary hypothesis that women's collegiate volleyball athletes swing more during practices than in matches. The higher average number of serves in the pre-season and the greater frequency of musculoskeletal injuries requiring participation restriction or removal from participation suggest that a concordant relationship may exist between workload and injury variables.

Level of Evidence: 2

Keywords: Attack, overuse, shoulder, volume, volleyball serve

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Funding: None
Conflict of Interest: All authors have no conflict of interest related to this manuscript

Acknowledgement: The authors' would like to thank the University of Kentucky Volleyball athletes and coaches for their assistance in this research project; in particular, the head coach Craig Skinner.

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DOI: 10.26603/ijspt20190088

INTRODUCTION

It is estimated that over thirteen thousand female athletes participate in volleyball at the collegiate level.[1] Musculoskeletal injuries result in significant time loss and limitations for these athletes.[2-4] The overall injury rates for volleyball have been calculated as 4.58 per 1000 hours of matches played and 4.10 per 1000 hours of practice.[1] The overall injury rate for women's volleyball athletes is 7.48 per 1000 athlete exposures.[5] The top three most common musculoskeletal injuries reported in women's collegiate volleyball are ankle sprains, knee internal derangements, and shoulder muscle-tendon strains.[1,5]

The overuse injury incidence rate for volleyball has been estimated at 0.6 per 1000 hours of participation.[4] This is an underestimate because overuse injuries are often under-reported due to most studies defining injuries as events involving time loss.[6] Baugh et al. calculated the non-time-loss injury rate in collegiate women's volleyball as 4.24 per 1000 athletic exposures.[5] Previous research indicates that shoulder overuse injuries account for 16-32% of all volleyball overuse injuries.[4,7] Even athletes who are not experiencing time loss may be experiencing limitations. In a survey of 2,352 volleyball athletes, 46% reported shoulder pain interfered with their ability to play.[2] Seventy-seven percent of 30 surveyed volleyball attackers reported that their shoulder pain limited where they could place the attack shot on the court.[3]

The pitching motion used in baseball is well documented to contribute to overuse injuries when performed in excess.[8-10] The overhead swing motion utilized by volleyball athletes to attack and serve the ball is thought to have a similar relationship to injury because of biomechanical similarities to the baseball pitching motion.[11-15] Both the baseball pitch and volleyball swing place high demands on shoulder musculature.[11] Maximal internal rotation velocity is similar between the two motions with baseball players reaching velocities between 6000-7000°/sec compared to volleyball swings reaching 4520 ± 1020°/sec.[12,15] Maximal internal torques during volleyball serve (40Nm) are approximately two-thirds that of pitching (67Nm).[12,14] If these mechanical demands are part of the cause of the high incidence of shoulder injuries in baseball and volleyball, the volumes of overhead arm swings may be another aspect of this explanation.

The concept of overuse injuries requires that first typical use must be defined. In youth baseball, research has demonstrated that pitching volumes exceeding 75 pitches in a single game increase the risk of injury to the upper extremity.[9] While the mechanics of the volleyball swing are known to be comparable to those of a baseball pitching, the volumes of volleyball swings, have not been extensively studied.

Two previous studies have examined swing volume in volleyball athletes. Hurd et al. [16] counted the number of swings that occurred over the course of seven seasons using match statistics from a single Division I collegiate women's volleyball team. The number of swings varied by position but ranged between 5-7 swings per game per player. Mayers et al., [17] estimated the total number of attacks and serves performed by an entire team during a match to be approximately 200 overhead swings using match statistics from multiple collegiate teams. Mayers et al. [17] also estimated practice volumes collected during a single practice session. While these studies provide insight into the number of swings volleyball players are exposed to over the course of a season, they are primarily based primarily on match statistics and do not track musculoskeletal injuries. Further, a single practice to estimate what happens over the course of a season is unlikely to provide an adequate estimate of practice hit and serve volumes.

Therefore, to better understand the typical volume of overhead swings and injuries reported over the course of a volleyball season, a two-year prospective cohort study to record these events during both practices and matches in a single Division I collegiate women's volleyball team was performed. The purpose of the current study is to provide a complete depiction of typical overhead swings, serves, and hits, which occur in both practices and matches. The primary hypothesis was that significantly more swings would occur in practices compared to matches. The secondary hypothesis was that greater swing volume and greater shoulder related musculoskeletal injury frequency would occur in the preseason than the season. A consistent occurrence or

concordant behavior between these two variables may suggest they could be related.

METHODS

Participants

Each participant read and signed a university IRB approved consent form prior to data collection. Inclusion criteria for this study consisted of being a member of the University of Kentucky Division I women's volleyball team. No participant asked to be excluded from the study; therefore, we collected swing and serve counts from 19 athletes over a two-year window. Seven players were outside hitters, four were middle blockers, five were defensive specialists, and three were setters. Eight of the 19 athletes participated in both years of data collection. Participants were 19 $\pm$ 1 years old, 1.8 $\pm$ .08m tall and weighed 73.47 $\pm$ 9.43kg.

Data Collection

Each participant's position, number of hits, number of serves, and participation status were recorded daily for two seasons. Data were collected from practices and matches during the fall 2014 and 2015 seasons. Participant position was determined using the team's online roster. Researchers attended or watched a digital video of practices and matches and counted each time every player hit or served the ball. Warm-up prior to matches were included in this study. The number of total swings was calculated by summing the hit and serve values.

A serve was recorded any time a participant initiated play by hitting the ball using an overhead motion from the end-line. A hit was recorded any other time a participant used a forceful overhead arm swing attempting to move the ball over the net; in previous studies, hits have been defined as "attacks" or spikes" but are the same arm motion that is described as hits in this study. The sum of hits and serves was also recorded and was labeled "swings." The researcher's reliability for counting each type of overhead swing was assessed by watching five of the recorded events a second time. The counts from this second trial were compared to the same events counts recorded during the data collection period to determine the intraclass correlation coefficient (ICC). Serve ICC was .998 (CI_{95} .996, .999) with a standard error of measurement = 0.52, hit ICC was .986 (CI_{95} .977, .991) with a standard error of measurement = 1.64, and total swings ICC was .989 (CI_{95} .982, .993) with a standard error of measurement = 1.80.

Volleyball activities were documented daily. Volleyball activities included matches, practices, and off-days. A match event was identified when the team participated in match competition. A match included all of the sets played in a single match. Practice was recorded when the team completed a mandatory, full-team practice. Rest-day was recorded any time when there was no practice or match. On some days, two volleyball activities would occur, either two practices, two matches, or practice and match. During each volleyball activity, the serve and hit data were recorded separately by player and event. Matches were accounted for using the team's schedule. All other days were counted as practices unless the staff athletic trainer indicated it was a rest day.

The athlete's injury status was recorded by the team's certified athletic trainer for every event. Standard practice was to categorize injury status into four conditions: full participation, full participation but athlete reported some issue was occurring, limited participation due to injury, no participation due to injury. These four categories were further collapsed into two categories: full participation (combined the two full categories) or limited participation (combined limited and no participation categories) for statistical analysis of shoulder related injuries. Event and participation status were confirmed by the team's athletic trainer to assure the data was accurately recorded. An attempt was made to capture all events, but this was not always possible due to practice times being changed, video recording not available, and the research team member not available to capture data.

Data Analysis

The volume of serves, attacks, and swings for the two seasons were the dependent measures and averaged for the two independent variables of events and position. Event had two levels: practice and matches. Position had four levels: middle blocker, outside hitter, defensive specialist, and setter. Three separate 4x2 univariate ANOVAs were completed, one for each dependent variable. Significance value was set

at $p \leq 0.05$. Bonferroni post-hoc analysis compared pairwise differences between dependent variables with significance set at $p < 0.05$ when appropriate. Data were analyzed using SPSS version 22 (IBM, Armonk, NY).

To investigate the relationship between musculoskeletal injuries and swing volume the following steps were undertaken. First, average swings per session were used for statistical analysis as it summed both hits and serves into one value that was averaged across all positions. The season was broken up into two components; pre-season and competitive season. Pre-season accounted for two weeks of practice for both years and included all practices and inter-squad scrimmages prior to competitions against other teams. The season averaged 17 weeks for both years and included all practices, non-conference, conference, and tournament competitions. Next, a one way ANOVA was performed to determine if the mean number of swings per session was different between the pre-season and the season. Next, a Pearson Chi-Square test was used to determine if the proportion of shoulder injury status differed between seasons. Injury status was defined as full participation (full participation + full participation but athlete reported some issue was occurring) or limited participation (limited participation due to injury + no participation due to injury). Season had two levels pre-season or season. All analysis was set with significance set at $p < 0.05$ using JMP version 12, SAS Institute, Cary, NC.

Results

Researchers captured data from approximately 75% of all volleyball activities across two seasons (Table 1). Practice events make up the majority of these missed events due to scheduling changes and conflicts between members of the research team available to collect the video recording of the practice. These missed practices occurred throughout the year missing 1-2 practices per week with the highest number of missing occurring in the early part of the first year due to scheduling conflicts. Excluding off-days and non-shoulder injuries, 222 volleyball activities occurred during the study period; 65 (29%) activities were matches, and 157 (71%) activities were practices accounting for a total of 2098 athletic exposures. The duration of matches averaged 110 ± 27 minutes which was similar to practice (121 ± 37 minutes) supporting that average data could be compared statistically without risk of duration bias.

Table 1. *Number of Events by Type.*

Event	Captured (%)	Not Captured (%)	Total
Game	54 (83.1)	11 (16.9)	65
Practice	112 (71.3)	45 (28.7)	157
Total	166 (74.8)	56 (25.2)	222

Captured-Data was collected for the event, Not Captured-No data was collected for the event

Table 2. *Descriptive Statistics for Position by Event.*

Position	Event (SD)	Serves (SD)	Hits (SD)	Swings (SD)
S	Practice	23 (18)	14 (13)	37 (24)
	Game	12 (8)	7 (10)	19 (13)
OH	Practice	21 (19)	29 (20)	50 (33)
	Game	10 (10)	27 (19)	37 (26)
MB	Practice	19 (14)	29 (20)	48 (27)
	Game	7 (8)	16 (13)	22 (16)
DS	Practice	27 (23)	12 (12)	40 (28)
	Game	12 (10)	8 (11)	20 (14)

S- Setter, OH-Outside Hitter, MB-Middle Blocker, DS-Defensive Specialist Serves-mean number of serves completed per event, Hits-mean number of overhead hits completed per event, Swings is the sum of servers and hits occurring during an event-mean number of swings completed per event, SD-standard deviation

Descriptive statistics for serves by event and position are presented as means and standard deviations in Table 2. An ANOVA for serves revealed no significant interaction for events by position ($p = 0.13$) There was a main effect for event, indicating on average, more serves occurred during practice 23 (CI_{95} 22, 24) than during matches 10 (CI_{95} 9, 11) regardless of player position ($p < 0.001$). The ANOVA for serves also revealed a main effect for position ($p < 0.001$), Bonferroni post-hoc analysis revealed that middle blockers serve less than all other positions and that outside hitters' served less than defensive specialists regardless of the event. (Figure 1).

Descriptive statistics for hits are presented as means and standard deviations by position and event in Table 2. An ANOVA for hits resulted in an interaction for event by position ($p < 0.01$). Bonferroni post-hoc analysis revealed that setters, middle blockers, and defensive specialists performed significantly more hits during practice than during matches. Only outside hitters performed the same number of overhead hits in matches as in practice. (Figure 2).

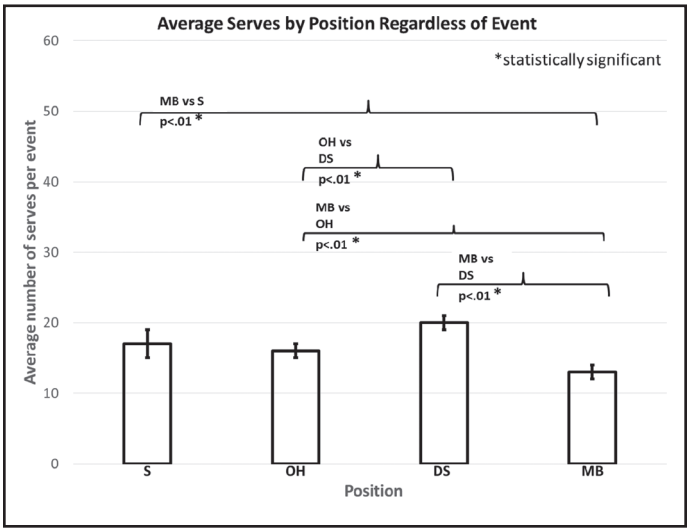

Figure 1. *Represents the main effect comparisons of serves across all positions demonstrating that middle blockers served the least. Error bars represent 95% confidence intervals.*

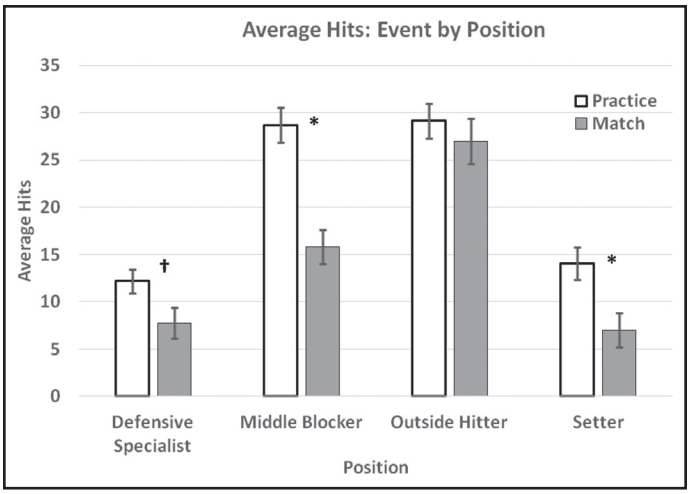

Figure 2. *Represent the post-hoc analysis of the interaction between practice and matches. This graph illustrates average volume of hits, comparing practice to match by position. All positions perform more hits in practice than in matches except for outside hitters. Error bars represent 95% confidence intervals.*
** Indicates a significant difference in average hits between events ($p < 0.001$)*
† Indicates a significant difference in average hits between events ($p = 0.02$)

Descriptive statistics for swings (serves + hits) are presented as means and standard deviations by position and event in Table 2. The ANOVA model resulted in interaction for the event by position ($p = .002$). Bonferroni post-hoc analyses identified

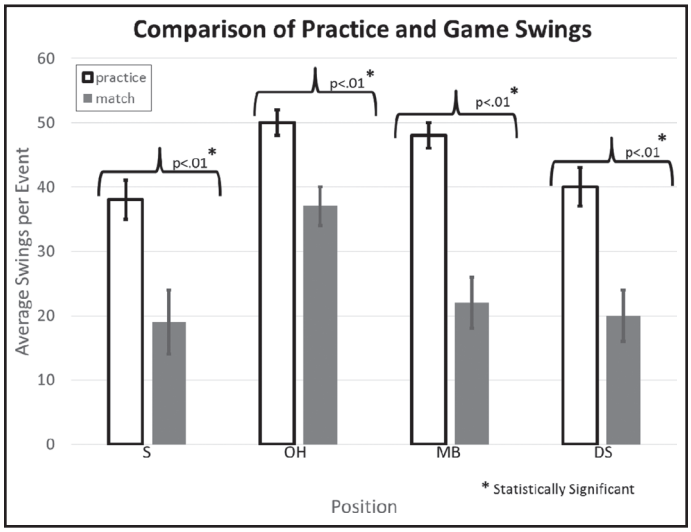

Figure 3. *Represents the interaction between practices and games, demonstrating a greater number of swings (swings represents hits plus serves) occur in practices than in matches for all positions, Error bars represent 95% confidence intervals.*

that in each position an average of 19 more swings occurred in practice compared to matches. ($p < .01$, Figure 3). The volleyball players averaged nearly twice as many swings in practice as in matches.

Pre-season average swings per session 47.1 (CI_{95} 44.1, 50.1) was significantly greater than average swings per session during the competitive season 37.7 (CI_{95} 36.4, 38.9) ($p < 0.001$) resulting in a mean difference of 9.4 (CI_{95} 6.1, 12.7) swings. There were 2098 total athletic exposures across both pre-season and season for the two years. The certified athletic trainer recorded 36 exposures in which the players were either limited or not able to participate due to a shoulder related musculoskeletal injury for the entire season. The Chi-square test for independence revealed that the proportion of injury status differed significantly between pre-season and competitive season ($p < 0.027$) with a significantly greater probability of being in the limited participation category during the pre-season (2.9%) than during the season (1.1%) (Table 3).

DISCUSSION

The primary purpose of this study was to provide a comprehensive understanding of collegiate women's volleyball players' workload by quantifying the number of swings performed in a season. Particular

Table 3. *Proportion of Injury Status (Full or Limited Participation) by Season.*

		Full Participation	Limited Participation	Total Events
Pre-Season	Counts*	409	12	421
	% of Row	97.15	2.85	100
Competitive Season	Counts*	1653	24	1677
	% of Row	98.57	1.1	100

% = Percentage
% of Row represents the athletic exposure count as percentage of the row total.
The events, practices and games are combined across the two years of data collection to accounts for the 2098 events.
**Counts represent the number of athletic exposures for each level of participation*

Table 4. *Comparison of Return Progression to Average Practice Volumes.*

Position	Swing Type	Hurd et al., [16] RTP Volume	Current Study Practice Volume
MB	Serves	20	32
	Hits	32	29
	Total	52	61
OH	Serves	20	48
	Hits	48	29
	Total	68	77
S	Serves	24	16
	Hits	16	14
	Total	40	30

Hurd et al.,[16] in Table 2 of their publication describe the number of swings by type, serves or hits in the final step of a proposed return to play (RTP) program.. Current Study Practice Volume-mean volume per player in a typical practice from the current study's data, MB-middle blocker, OH-outside hitter, S-setter. Hurd et al.[16] did not have a middle blocker categorization but for comparison their data from middle attacker was used.

attention was given to practice swing volume, as it has not been previously recorded in this level of detail. The frequency of time loss and non-time loss injuries was greater during the pre-season over the regular competitive season which follows a concordant pattern of total swing volume being greater in the pre-season than the competitive season. These findings bring attention to a characteristic pattern of two variables that have been found to be related in other studies, but this study design does not allow a direct relationship between cause and effect to be determined.

The results revealed that significantly more swings occur in practice than in matches. Match swing volumes from the current study agree with match volumes previously reported in the literature.[16] The current study agrees with previous research that during a typical match, overhead swing volume will range between 20-40 swings per match dependent on position. The current study supports the volume of serves and hits recommended in the interval hitting program developed by Hurd et al.[16] Although this interval program was developed using only match counts, the values utilized in the program align reasonably well with the current study's findings when taking into consideration the total number of overhead motions, both serves and hits combined. There was about a 10 swing difference which is primarily accounted for by the current study using practice data to compare to Hurd's match data. In the current study, there was an observed difference of 19 more swings in practice compared to matches which likely accounts for the differences. The direct comparison for outside hitters revealed 19 hits in Hurd's interval program compared to the current study but this offset as 28 more serves were recorded in the current study resulting in only nine total swing differences. The return to play protocol would still sufficiently prepare athletes for returning safely to both practice and match demands (Table 4). These two studies were completed on different teams with

different coaches and years apart from each other but yielded similar results suggesting that these are relatively consistent swing volumes for women's collegiate volleyball.

The total seasonal volume of hits and serves were higher in the current study compared to previous values reported by Mayers.[17] They reported an average of 4,346 ± 585 hits and 2,824 ± 468 serves that occurred during matches in a typical 12 week season.[17] These data were accumulated across all positions. Analysis of the current study's data across all positions averaged across the two seasons revealed 1500 more hits and 670 serves than previously reported. The differing values may be due to coaching and playing styles or season length; it is most likely due to the method of data collection used in each study. The current study involved a researcher counting the number of overhead swings while the previous study used match statistic estimates to determine the number of overhead swings. The current study contributes new knowledge that a women's collegiate athlete will perform 35-50 swings per practice dependent on position during a typical 30 + match season.

The second aim of the current study was to investigate the potential relationship between swing volume and shoulder related musculoskeletal injuries. Although the current study is limited to a single team over two seasons, there appears to be a pattern and potential relationship between swing volume and musculoskeletal injury status with a higher proportion of reported injury, limited participation or complete removal from participation occurring in the pre-season during the first two weeks of both seasons. These findings agree with previous research; Baugh et al.,[5] reported the injury rate during women's volleyball pre-season was nearly double the regular season injury rate (10.43 vs. 5.99 per 1000 athletic exposures). These findings need to be brought to coaches' attention mainly due to the high incidence of reported shoulder pain in volleyball players.[3,7,16] Cause and effect cannot be established with a single study; however, the high pre-season swing volume may be a contributing factor to the pre-season injury incidence.

In order to further investigate the relationship between season and injury, a Chi-Square analysis was performed. A Chi-Square analysis tests the independence of the variables, in this study these were two categorical variables season and injury status. In this study, the statistical analysis compared the proportion of injury status across the two components of the season. The results indicated that these two variables are not independent, as there was a significant finding indicating that the two variables had some dependence on each other. It is important to remember that this analysis does not enable the research to determine cause and effect. The data indicates that there are proportionally more reported injuries during the pre-season than during the competitive season. Further, athletes completed an average number of 47 swings (serves + hits) in the pre-season compared to 37 swings during the regular competitive season. This would suggest that the workload on the athlete was higher in the pre-season. The large volume of practices occurring during the pre-season likely accounts for the high average swing volume. These data would suggest that there appears to be some type of relationship between swing volume and reported musculoskeletal injury but cannot establish a true relationship. This study was undertaken to investigate the potential that the relationship exists. It provides preliminary evidence that a more extensive research project should be undertaken to determine if a true relationship between swing volume and injury status are related in collegiate volleyball as has been done in youth baseball.[8-10,18]

Similar patterns of workload and injuries have been noted in rugby where the workload was measured in the distance covered via GPS systems.[19,20] Studies of workloads in rugby have shown that reducing pre-season training volumes resulted in reduced injury rates while still adequately preparing athletes for the demand of a season.[21] While the demands of volleyball and rugby are very different, it may be useful to examine reducing pre-season swing volumes to see if there is a reduction in injury.

The current study is unique because arm swings were visually counted during practices and matches rather than gathered only from matches or estimated from a single practice observation. Utilizing the team's athletic trainer to track both time-loss and non-time-loss injuries add clinical relevance to this

study. Overuse injuries can be debilitating and lead to time loss injuries[4,7] but are more commonly managed by modifying activities or limiting drills rather than removing the athlete from play. The nearly 2% increase proportion of players participating as limited status during the pre-season compared to the season may be a result of workload or potentially the single athletic trainer protecting the athlete for the upcoming season. Since only one team was used in this study, the external validity is limited. However, high workload volumes in overhead sports have been observed to result in greater likelihood of upper extremity overuse injuries when acute increases in workload occurred.[22,23] This is what was observed in the current study, during pre-season volleyball training.

Volleyball is one sport where the injury rate in practice is nearly the same as it is in competitions.[1] However, the swing workload volumes occurring during practice are rarely taken into consideration when accounting for overhead motions and could explain the practice injury rate to approach the match injury rate. This study was unique, as swing volume during practice was included and revealed that across nearly all positions double the number of swings were occurring during practice. As practices and matches both averaged two hours long this increase in volume is not accounted for with an increase in time. The additional focus on practice data in the current study was critical to capture an accurate assessment of overhead motions occurring to collegiate volleyball athletes.

LIMITATIONS

The present study has limitations. Only one NCAA Division I team was observed in this study; therefore, the results may not apply to teams at other levels due to different coaching and playing styles. However, the swing volumes were similar to those collected from another Division I team. Researchers made every attempt to record all events over the course of the season, but 25% of events were unable to be recorded, which were primarily practices. The missing events does not have a substantial impact on the results as the data was averaged on 112 out of 154 potential practices over the course of two years were recorded in this data set. However, to the authors' knowledge, the current study represents the most complete swing volume estimate to date. The decision to limit or allow full participation was based on a single athletic trainer which may bias the result of this study on one team and potentially limit the external validity of this study. The dependence between season and injury status only suggest a relationship may exist between the increased workload during the pre-season and competitive season. A more extensive study examining the direct relationship between swing volume and injury history that incorporates a variety of coaching styles would be necessary to establish if a relationship exists between swing volume and musculoskeletal injury occurrence.

CONCLUSIONS

Women volleyball athletes perform approximately twice as many overhead swings in practices than in matches. Coaches and health care providers need to consider swing volume beyond those occurring during matches as this underestimates actual swing volume for an athlete. The volume found in this study can be considered the best estimate to date of overhead swing volume in Division I collegiate women's volleyball teams. There appears to be a proportionally higher volume of non-time loss injuries during the pre-season. Coaches and health care providers can potentially use this finding to coordinate their training volume better to potentially reduce musculoskeletal injuries. Further research is needed to examine if overtraining causes injury.

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