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Jump frequency may contribute to risk of jumper's knee: A study of inter-individual and sex differences in a total of 11 943 jumps video-recorded during training and matches in young elite volleyball players

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ABSTRACT

Background: Male sex, total training volume (# of hours per week) and match exposure (# of sets played per week) are risk factors for jumper's knee among young elite volleyball players (Visnes & Bahr, 2012). However, it is not known whether jump frequency differs among players on the same squad.

Objective: To examine inter-individual and sex differences in jump frequency during training and matches in young elite volleyball players.

Design: Observational study.

Setting: Norwegian elite volleyball boarding school training program.

Participants: Student-athletes (26 boys and 18 girls, 16-18 yrs).

Methods: Individual jump counts were recorded based on visual analysis of video recordings obtained from one week of volleyball training (9 training sessions for boys and 10 for girls, 14.1 h and 17.8 h of training, respectively) and 10 matches (5.9 h for boys (16 sets) and 7.7 h for girls (21 sets).

Results: A total of 11943 jumps were recorded, 4138 during matches and 7805 during training. As training attendance and jump frequency varied substantially between players, the total exposure in training ranged from 50 to 666 jumps/week among boys and from 11 to 251 jumps/week among girls. On average, this corresponded to 35.7 jumps/h for boys and 13.7 jumps/h for girls (t-test, $p=0.002$). Total jump exposure during matches ranged between 1 to 339 jumps among boys and between 0 to 379 jumps among girls, corresponding to an average jump frequency of 62.2 jumps/h for boys and 41.9 jumps/h for girls (t-test, $p<0.039$). The inter-individual differences in jump frequency were substantially greater than any differences observed among player functions.

Conclusions: Jump frequency has substantial inter-individual and sex differences during training and matches in young elite volleyball players. Total jump volume may represent a more important risk factor for jumper's knee than total training volume, warranting further research attention.

INTRODUCTION

Patellar tendinopathy is a common overuse injury in sports with high demands on rapid force development in the leg extensors. It is generally known as jumper's knee, an appropriate term according to a cross-sectional survey by Lian *et al.*[1] The prevalence of jumper's knee among elite athletes across 9 different sports was closely related to knee extensor loading patterns. Jumping is an integral part of volleyball and basketball, where 45% and 32% of players were affected.

The risk of developing jumper's knee is closely related to how much[2] and how high[3-7] a player jumps. In young, elite volleyball players, one extra training hour and one extra set of match play per week increased the risk of developing jumper's knee by a factor of 1.7 and 3.9, respectively.[2] Also, players who developed jumper's knee jumped 10% higher in jump tests than those who did not, the so-called "jumper's knee paradox".[3] However, these studies have not accounted for the frequency of jumps, only the total amount of training and match play. One hour of training for one athlete may represent a substantially different number of jumps from one hour of training for another athlete, even among players within the same squad.

Sex is another risk factor for jumper's knee. Among Norwegian elite football and handball players, 2.5 times as many males had jumper's knee compared to females practicing the same sport.[1]. Zwerver *et al*., interviewing non-elite athletes from 7 different sports in the Netherlands, also found an increased risk among males.[8] Visnes *et al*., in their prospective study on young elite volleyball players, showed that males had a four times higher risk of developing jumper's knee as the females attending the same program.[2 3] Interestingly, across these studies, there is little or no difference in total training volume between sexes. One possible explanation of the sex bias is that males jump higher than females, and therefore subject their patellar tendons to higher loads.[3] Another explanation might be that studies have not accounted for the frequency of jumps, only the total volume of training.

Thus, we examined inter-individual and sex differences in jump frequency during training and matches in young elite volleyball players.

METHODS

Participants for this study were 2nd- and 3rd-year students in the Toppvolley Norge (TVN) volleyball program. TVN is located in Sand, Norway and combines an elite volleyball train-

ing program with a three-year senior high school boarding school program. The students start at the age of 15-16 years, and are expected to complete 3 years for a college-entry baccalaureate degree, although some students enter the program directly in the second or third year. TVN aims to recruit the most talented junior volleyball players in Norway.

On average, the school recruits 12 boys and 12 girls each year, which means that apx. 72 students attend the TVN program each year. The school team participates in the national league at the second highest level with women's and men's teams, each playing a 6-8 team round robin competition with home and away matches from October through March, as well as three weekend tournaments with 16-20 teams and 5 matches per team. The athletes also represent their home clubs in the Norwegian national leagues and junior volleyball competitions at various levels.

Training is organized in three training groups where students usually train with their classmates. In a typical week, they have 2-3 volleyball sessions before school in the morning and 3-4 volleyball sessions after school in the afternoon. For some sessions two training groups train together using up to 3 courts. Other strength and fitness training is done on an individual basis. Coaches are full-time professionals, recruited from Norway, Japan, Serbia and Brazil.

Coaches were asked to videotape all training sessions for training groups 2 (mainly 2nd year students) and 3 (mainly 3rd year students) during one training week mid-season in January 2011. They were informed that the videos would be used for analyses, but were not informed of the purpose of the study. In addition, we obtained videos of 5 regular league matches played by each of the Div. 2 teams, men and women. Matches are played best out of 5 sets according to the official FIVB rules of the game[9] with a maximum of 12 players selected for each match.

Training and match videos were reviewed and each jump was registered with the identity of the athlete, the type of skill performed (serving, passing, setting, attacking, blocking, backcourt defense, as well as warm-up jumps which could not be related to a particular skill), the intensity of the jump (hop, submaximal, maximal), landing strategy (balanced on both feet, on right or left foot). In addition, we asked the coaches to classify the main playing function of each player (setter, middle blocker, outside hitter, diagonal, libero). For the matches, we also obtained score sheets with information on scoring and player participation.

The players were included in a 5-year prospective cohort study where they had been examined every 6 months for jumper's knee, defined as a history of pain in the quadriceps or patellar tendons at their patellar insertions in connection with training or competition, and tenderness to palpation corresponding to the painful area.

We calculated jump frequency as the number of jumps performed by each player divided by the number of hours of training and match attendance for each player.

RESULTS

Training exposure

Video recording were obtained from a total of 9 training sessions for boys and 10 for girls, covering a total of 14.1 h and 17.8 h of training, respectively. The sessions involved 26 boys (12 diagnosed with jumper's knee at some point during their stay at TVN) and 18 girls (1 with jumper's knee). Attendance varied between training sessions, and on average males participated in 4.2 sessions (range: 1 through 7) and females 5.4 sessions (range: 2 through 8). The total number of player training sessions was 108 for boys and 98 for girls.

A total of 7805 jumps were recorded during training, 4993 among boys and 2812 among girls. As training attendance and jump frequency varied substantially between players, the total exposure in training ranged between 50 and 666 jumps/week among boys and between 11 and 251 jumps/week among girls. On average, this corresponded to 35.7 jumps/h for boys and 13.7 jumps/h for girls (t-test, p=0.002). There was no difference in jump frequency between boys with and without jumper's knee (p=0.28). The relationship between player position and jump frequency is shown in Table 1. We observed a difference in jump frequency between player functions among boys (ANOVA, p=0.008), but not among girls (p=0.99).

Table 1 Relationship between player position, sex and jump frequency in training. Jump frequency is expressed as the number of jumps per hour of training.

	Boys				Girls			
	N	Mean	Range		N	Mean	Range	
Diagonal	6	26.8	11.7	45.5	1	14.2	-	-
Outside hitter	5	23.2	10.2	36.8	8	13.9	2.9	20.9

Libero	4	14.5	5.7	29.2	3	13.7	9.7	16.8
Middle block-er	8	45.9	28.3	91.0	2	12.3	11.5	13.2
Setter	3	63.9	20.3	128.2	4	13.7	10.5	21.5
Total	26	35.7			18	13.7		

As shown in Figure 1, the distribution of skills performed when jumping differs between player functions among boys, but not among girls. The pattern also differs between boys and girls.

(Figure 1 near here)

Among boys, 10.2% of jumps were classified as hops, 20.6% as submaximal jumps and 69.1% as maximal jumps. The corresponding figures for girls were 1.4%, 10.9% and 87.7%. For both sexes, the majority of landings were on both feet (boys: 94.2%, girls: 94.5%).

Match exposure

Five matches for each sex were analyzed, covering a total of 13.6 h of match play, 5.9 h for boys (16 sets) and 7.7 h for girls (21 sets). Of the training groups covered by the video study, 20 of 26 boys and 16 of 18 girls were selected for the 5 matches.

A total of 4138 jumps were recorded during the 10 matches, 2202 among boys and 1936 among girls. As playing time varied substantially between players, the total exposure in the 5 matches ranged between 1 and 339 jumps among boys and between 0 and 379 jumps among girls. Player jump frequency averaged 62.2 jumps/h for boys (corresponding to an average total of 138 jumps per set for the team) and 41.9 jumps/h for girls (total of 92 jumps per set).

The relationship between player position and jump frequency during match play is shown in Table 2. We did not detect a difference in jump frequency between player functions among boys (ANOVA, $p=0.089$) or among girls ($p=0.32$), but jump frequency was higher among boys than girls (t-test, $p<0.039$).

Table 2 Relationship between player function, sex and jump frequency during match play. Jump frequency is expressed as the number of jumps per set for the 12 players selected for each match.

	Boys				Girls			
	N	Mean	Range		N	Mean	Range	
Diagonal	4	9.1	2.0	17.0	1	14.7	-	-
Outside hitter	5	7.1	0.6	14.0	6	5.0	0.0	11.3
Libero	2	0.3	0.3	0.3	2	0.2	0.0	0.3
Middle blocker	6	13.0	1.7	26.1	3	10.2	3.1	14.2
Setter	3	15.7	13.9	21.5	4	5.3	0.0	18.0
Total	20	10.2			18	6.0		

As shown in Figure 2, the distribution of skills performed when jumping differs between player functions among boys and girls. The pattern also differs between boys and girls.

(Figure 2 near here)

Among boys, 3.7% of jumps were classified as hops, 32.2% as submaximal jumps and 64.0% as maximal jumps. The corresponding figures for girls were 0.2%, 18.8% and 81.0%. For both sexes, the majority of landings were on both feet (boys: 94.3%, girls: 97.2%).

DISCUSSION

This is the first study to compare jump frequency among volleyball players within the same elite development program. We found much greater inter-individual and sex differences in jump frequency during training and matches than expected.

Is 'training volume' a surrogate for the more important risk factor 'jumping'?

Training volume and match participation represent strong risk factors for jumper's knee.[2] The explanation for the difference in training and match exposure was that many of the athletes affected were selected for different training camps with junior national teams or their home clubs on weekends and school holidays.[2] In other words, they were the most talented players. The differences we have observed in jump frequency during match play are easily explained; the best players see more playing time and get more hits, blocks and sets. But also during training it seems that skill level is a key factor. The best players are more likely to be given central roles, especially when the coach is drilling his starting six, and with their skills they are also more likely to stay on court in drills where the winner gets to keep going. It

should be noted that even if player function was a significant factor among boys, the between-player differences where larger than those observed between player functions (table 1). During match play, there were no differences between player functions. This is in contrast to findings by Sheppard et al.[10] of 16 international top level matches (2004 Olympic Games and international test matches). It is possible that an even larger sample size would have revealed differences between player functions during match play in our study as well. A cross-sectional survey among 18-35 year old Dutch volleyball players from different levels revealed that outside hitters and middle blockers were at greater risk for developing jumper's knee than setters,[11] as originally shown by Lian et al, possibly because they tend to be taller, heavier and jump higher. [5] Nevertheless, the current study documents that there are differences in jump frequency between players that could amplify the differences reported in total training and match exposure, and therefore exacerbate the risk for developing jumper's knee. However, to establish this link, prospective studies based on individual jump counts are needed.

Does the weekly jump rate contribute to the risk factor 'sex'?

Several epidemiological studies have shown that sex is another risk factor for jumper's knee.[1-3, 8] In fact, Visnes *et al*. [2-3] have shown that the male-to-female risk ratio was 4:1 in the total TVN cohort, and in the sample participating in the current study 12 of 26 boys were diagnosed with jumper's knee compared to only 1 of 18 girls. As there seems to be no difference in total training volume between sexes, the explanation favored for the sex bias is that males jump higher than females, subject their tendons to higher loads.[3] In the current study we show that males jump 2.6 times as much as females during training and 1.5 times as much during matches. Also, in the male group there was a greater disparity in jump frequency than within the female group. As can be seen from the player function patterns, the sex difference in jump frequency can at least partly be explained by differences in playing style with less jump setting and less involvement of the middle blockers in attacking and blocking among the girls in training, at least during training (see table 1 and figure 1). These findings could help explain the sex differences observed in jumper's knee prevalence. It seems that males are subjected to a much greater jump frequency during the vulnerable period transitioning from young talent to mature elite player, a phase were a large proportion of boys tend to develop tendon problems.

However, these two hypotheses, that jump frequency is related to the risk for jumper's knee and can help explain the sex bias, requires further research in prospective studies, where jump counts are measured as the exposure factor instead of just total training volume and match participation. In the current cross-sectional study, there was no difference in jump frequency between players with established jumper's knee and asymptomatic athletes. This is perhaps not surprising, as the study only covers only one week of training and a few matches. Players who are already symptomatic may also have been limited by knee pain. Other limitations include differences in training attendance and match selection, which we have corrected for by comparing jump frequency per hour of training or per set played. We did not inform coaches of the purpose of the study, so we expect the sample is representative of normal practice routines. While all players were Norwegian, the coaches represented some of the world's leading volleyball nations of the world, so it is unlikely that the large disparity in jump frequency is a local phenomenon. A possible limitation is the precision of the jump count, which was done by only one observer, although uniquely qualified as a national team player. With up to 12 people jumping at the same time, a jump might escape notice. He also subjectively classified jumps as maximal, submaximal and hops. Finally, the courts were not completely covered by the cameras, and jumps done in blind spots would be missed. However, it seems highly unlikely that these limitations could introduce systematic biases which would undermine the main conclusions.

Clinical implication: Are 'jump counts' a solution?

Baseball has introduced pitch counts to limit shoulder and elbow load in young and adolescent pitchers.[12] However, manual jump counting in volleyball is time consuming. Analyzing one hour of practice video took approximately 3 h if the drills were relatively simple, and up to 6 h if the drills were complex with many players jumping at the same time. Therefore, introducing routine jump counts in training would require the development of wearable technology to collect and analyze data.[13] In volleyball and other jumping sports, the best advice we currently can give is to keep a close eye on the most talented players, where their jumping ability is a key factor, to ensure that they are not overexposed to training and competition.[3 14 15]

CONCLUSION

There were substantial inter-individual and sex differences in jump frequency during training and matches in young elite volleyball players. Thus, jump frequency may represent an important risk factor for developing jumper’s knee.

WHAT IS KNOWN ON THIS SUBJECT

- Male sex, training volume and match exposure have been documented as risk factors for jumper's knee among young elite volleyball players.

WHAT ARE THE NEW FINDINGS

- One hour of volleyball training for one athlete does not equal one hour of training for another athlete; there are large inter-individual differences in jump frequency.
- Jump frequency is much higher for males than females among young elite volleyball players; this could partly explain the sex bias in the prevalence of jumper's knee.

HOW MIGHT IT IMPACT ON CLINICAL PRACTICE IN THE NEAR FUTURE

- Keep a close eye on the most talented players, where their jumping ability is a key factor, to ensure that they are not overexposed to training and competition. Methods to introduce routine jump counts in training are being developed.

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ETHICAL APPROVAL

This study has not been submitted for review by a medical research ethics committee.

CONTRIBUTORSHIP STATEMENT

RB designed the study, RB and MAB organized data collection and MAB analyzed the videos. RB and MAB jointly interpreted the data and wrote the paper. RB is responsible for the overall content as guarantor.

COMPETING INTERESTS

None.

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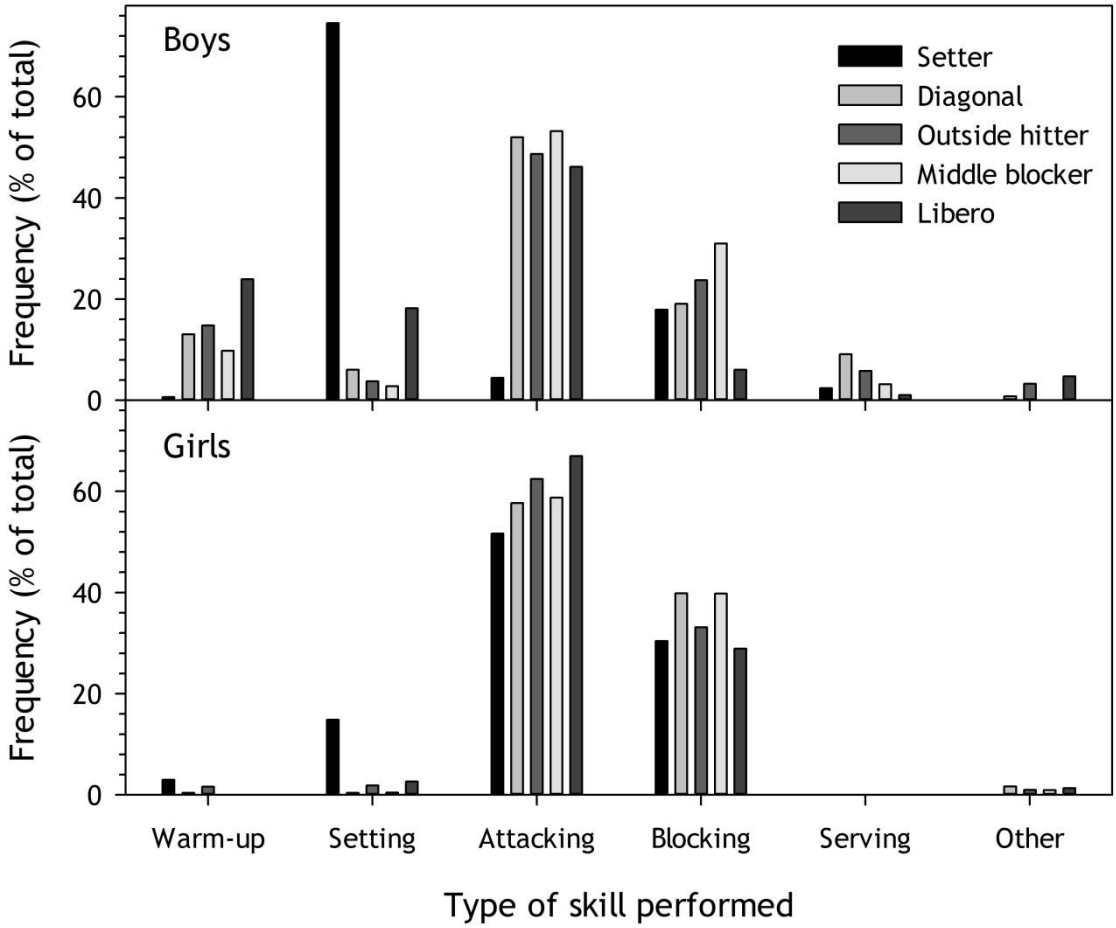
FIGURE LEGENDS

Figure 1 Distribution of skills performed when jumping during training related to player function. Boys are shown in the top panel, girls in the lower panel.

Figure 2 Distribution of skills performed when jumping during match play related to player function. Boys are shown in the top panel, girls in the lower panel.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Frequency (% of total)
Frequency (% of total)
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Warm-up
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Serving
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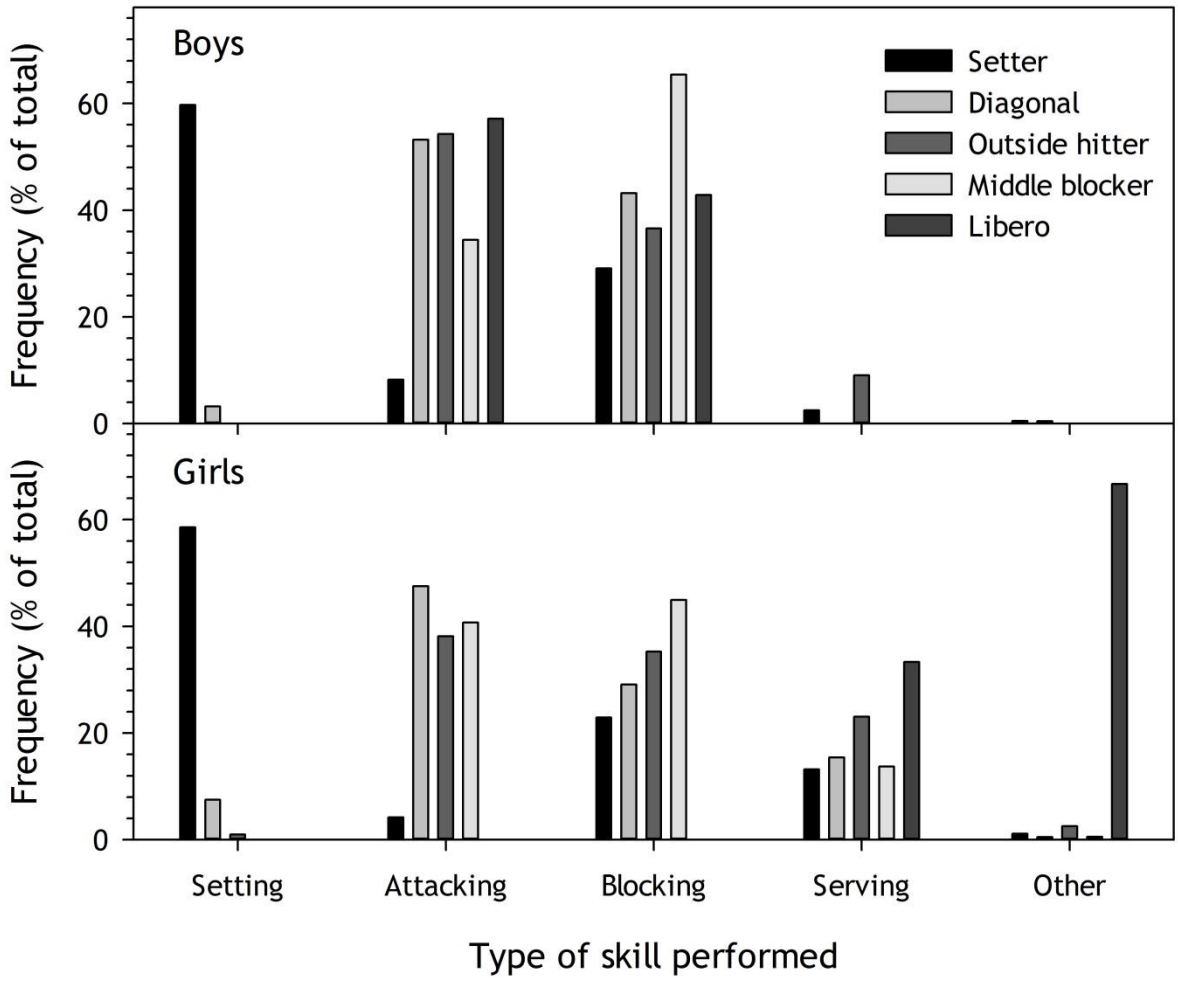
Type of skill performed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