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# **The jumper's knee paradox - Jumping ability is a risk factor for developing jumper's knee: a 5-year prospective study**

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## **Abstract**

**Background:** The “jumper’s knee paradox”, where symptomatic athletes appear to perform better in a counter movement jump (CMJ) compared to asymptomatic controls in previous case-control studies, is not fully understood.

**Aim:** The aim was to examine the relationship between jumping ability and change of jumping ability as potential risk factors for developing jumper’s knee.

**Methods:** 5-year prospective cohort study among elite volleyball players, aged 16-18. Jump tests were done on a portable force plate at the time of inclusion and semiannually. Jumper’s knee was diagnosed based on a standardized clinical examination.

**Results:** 150 students (68 males and 82 females) were included and 28 developed jumper’s knee (22 males and 6 females). At the time of inclusion, male athletes who went on to develop jumper’s knee had significantly better results in CMJ ( $38.0 \pm 5.8$  cm) compared to asymptomatic males ( $34.6 \pm 5.5$  cm,  $p=0.03$ ), while no difference was detected in standing jump (SJ: jumper’s knee:  $30.3 \pm 7.4$  cm, asymptomatic:  $28.1 \pm 6.1$  cm,  $p=0.23$ ). In a multivariate logistic regression analysis corrected for gender and previous volleyball training, the OR was 2.09 (1.03 to 4.25) per cm difference in CMJ at the time of inclusion. Our results did not reveal any significant differences in the change in jumping ability between the groups, although both groups improved their jump performance.

**Conclusion:** Volleyball players with a natural ability for jumping high are at an increased risk for developing jumper’s knee.

## ***Introduction***

The prevalence of jumper's knee is high, up to 40-50%, in sports characterized by high demands on leg extensor speed and power, such as volleyball.[1-3] Jumping plays an essential role in volleyball; key skills like spiking, blocking, serving and even setting involve jumping. These jumps are often maximal and, depending on their playing position, athletes could jump up to 300 times during a 5-game match.[4-6] Jumping ability is therefore an important criterion when selecting players. Studies show that players on a high level have higher vertical jump height compared to players at lower levels, e.g. counter movement jump (CMJ) was 10% higher among male first division than second division players in Belgium.[5-8] Such differences could be a consequence of not just selection and genetics, training obviously makes a difference. Sheppard et al.[9] described the changes in strength and power qualities over two years in players transitioning from juniors (mean age 18.5 years) to seniors. They concluded that to progress to the senior national team, players must increase their CMJ and spike jump through improving strength and speed strength, and develop high levels of stretch-load tolerance in stretch-shortening cycle activity. The optimal program for increasing vertical jump height is difficult to define, but a review from 2010 focused on explosive-type strength training and plyometric training as key elements.[10] Nevertheless, improvement is not always easy to achieve, and a well-trained Brazilian under-19 national volleyball team did not improve their CMJ or squat jump (SJ) during an 18-week training period prior to the under-19 World Championships.[11]

A recent study showed that athletes developing jumper's knee did more volleyball training and had a higher match exposure compared to those who remained asymptomatic.[12] Volleyball attracts tall athletes, but also athletes with a genetic predisposition to jumping high.[13] What we do not know is if athletes who naturally jump well have a higher risk for developing jumper's knee or if their jumping skills are the result of higher training loads. The jumper's knee paradox, where symptomatic athletes in case-control studies have performed substantially better in a CMJ compared to asymptomatic controls,[14-16] has never been explained properly. Therefore, the aim of this study was

to investigate jumping ability and change of jumping ability as potential risk factors for developing jumper's knee in a prospective cohort study.

## **Methods**

### **Subjects and setting**

Participants for this prospective cohort study were recruited among players entering the Toppvolley Norge (TVN) program. TVN is located in Sand, Norway and combines an elite volleyball training program with a three-year senior high school boarding school program. The students started at the age of 15-16 years, and they were expected to complete 3 years for a college-entry baccalaureate degree. Some students entered the program in the second or third year directly. TVN aimed to recruit the most talented junior volleyball players in Norway, and the athletes represented the school and their home clubs in the Norwegian national leagues at various levels.

The recruitment process began when school started every autumn with an information meeting. Potential participants were also informed in writing before their written consent was obtained, and also that of their parents if the athlete was younger than 18 years old. To be included, they had to be free of jumper's knee at the time of inclusion. The athletes were a part of the study as long as they attended TVN. The study was approved by the Regional Committee for Research Ethics and the Data Inspectorate.

### **Risk factors**

Height, weight and previous training, (volleyball, strength and other sports specific training the last season prior to inclusion in the cohort), were recorded as baseline data at the time of inclusion.

**Jumping ability.** Jump tests were done on a portable force plate (Musclelab 4000, Ergotest Innovation a.s., Porsgrunn, Norway) to estimate vertical jump height. The portable force plate has demonstrated to be a valid measure of vertical jumping ability.[17] Two types of jumps were tested, SJ and CMJ, and these tests are commonly used for testing elite athletes in different sports in Norway. SJ

were performed with the subject starting from a stationary semisquatting position with 90° of knee flexion and with both hands kept fixed on the hips. No counter movement was allowed with any body segment and the computer measured these movements and did not accept such attempts. In the CMJ the subject started the movement from a stationary erect position with knees fully extended, and was allowed to bend down to approximately 90° of knee flexion before starting the upward motion of the jump. This jump is a ballistic movement with rapid eccentric muscle action immediately followed by a maximal concentric contraction. Both hands were kept fixed on the hips.[15] The best out of three technically correct jumps was used for the final calculations. These tests were performed two times per year, first at the start of the school year (August/September) and the last 6 months later at the end of the volleyball season (March/April).

**Training volume.** Training volume was recorded prospectively on a weekly basis. We organized the registration on an individual basis through a web-based weekly training diary. Data were only collected during the 10-month school year, and the method has been described in detail previously.[12] We focused on change in jumping ability as a result of training volume, and did not include match exposure.

**Diagnosis.** The end point was a clinical diagnosis of jumper's knee. The following diagnostic criteria were used: 1) A history of pain in the quadriceps or patellar tendons at their patellar insertions in connection with training or competition, and 2) tenderness to palpation corresponding to the painful area.[2,15,18,19] In addition, all symptomatic athletes underwent a standard knee examination to exclude other diagnoses. Symptoms had to have been present for a minimum of 12 weeks. The athlete had to consider that the symptoms were sufficient to represent a substantial problem. The school physician and physiotherapist recorded cases prospectively, and the principal investigator (HV) visited TVN minimum twice a year (August/ September and March/April) to examine all athletes. At this time, all athletes also completed a VISA-P questionnaire.[20]

## Calculations and statistical methods

We used SPSS (version 18.0) to perform the analyses. The results from the jump tests are presented as the height of rise of the center of gravity (in cm), and we calculated the change in jump height the same way for asymptomatic and symptomatic athletes in two ways: 1) From baseline until 6 months after enrolment, and 2) from baseline to graduation. Training volume was calculated as the mean number of hours per week. Results are reported as the average  $\pm$  standard deviation unless otherwise noted. All potential risk factors were compared using unpaired t-tests examined in univariate analyses and those with a P-value  $<0.20$  were investigated further in a multivariate regression model. The final logistic regression analysis model included baseline data in the jump tests corrected for gender and previous volleyball training. Odds ratios for increased risk of jumper's knee are reported per cm difference in jump test results. We report Pearson coefficients for the correlation between training volume and change in jumping ability. P-values of  $<0.05$  were considered statistically significant.

## Results

The recruitment process is shown in figure 1. During the 5-year study period, 189 students were included and examined. Nineteen students were excluded when they entered the program due to pre-existing jumper's knee and 2 quit school before they had finished a full year. Nine students had to be excluded because no data were recorded, and some were excluded because a technical problem caused loss of data from testing during season 2, as shown in detail in figure 1.

The final sample consisted of 150 healthy students (68 males and 82 females) who were followed for 232 student-seasons, with a mean age at inclusion of  $16.7\pm 0.8$  years. On average, they attended TVN for  $1.6\pm 0.7$  years (1 year: 79 students, 2 years: 43, 3 years: 21, 4 years: 1).

In total, 28 out of the 150 athletes included developed jumper's knee during their time at TVN, 22 boys and 6 girls. In most cases, their symptoms stemmed from the proximal patellar tendon ( $n=25$ ); in

only 3 cases (2 males/1 female) were symptoms located in the distal quadriceps tendon. The VISA-P score at the first semiannual examination after diagnosis was  $72\pm 22$  points on the affected side for athletes with jumper's knee.

The healthy students were included in the cohort for  $1.6\pm 0.8$  years (males:  $1.6\pm 0.7$ , females:  $1.6\pm 0.8$ ). The injured group developed jumper's knee after  $0.8\pm 0.6$  years (males:  $0.8\pm 0.6$ , females:  $1.1\pm 0.6$ ) and they were followed as students at TVN for  $1.7\pm 0.8$  years (males:  $1.6\pm 0.7$ , females:  $1.7\pm 0.8$ ).

Baseline data are shown in table 1. There was no difference in height, weight and previous strength training between groups. However, we found that male athletes with jumper's knee reported more volleyball training and less other training prior to admission at TVN compared to the group that remained asymptomatic.

Table 1. Baseline data at inclusion and training volume (h/week) during the last season prior to inclusion in the cohort. Data are shown as the average  $\pm$  SD.

	Men					Women				
	N	Healthy	N	Jumper's knee	p-value	N	Healthy	N	Jumper's knee	p-value
Height (cm)	46	186 $\pm$ 6	22	187 $\pm$ 7	0.54	74	172 $\pm$ 6	6	173 $\pm$ 6	0.69
Weight (kg)	41	75 $\pm$ 9	20	77 $\pm$ 7	0.45	58	65 $\pm$ 8	6	66 $\pm$ 13	0.82
Volleyball (h/week)	43	8.0 $\pm$ 4.1	21	11.2 $\pm$ 6.1	0.04	69	7.7 $\pm$ 4.1	6	9.0 $\pm$ 4.9	0.48
Strength (h/week)	43	1.7 $\pm$ 2.5	18	2.2 $\pm$ 2.0	0.50	67	1.4 $\pm$ 1.6	6	1.8 $\pm$ 2.0	0.53
Other sports (h/week)	43	1.5 $\pm$ 2.3	18	0.3 $\pm$ 0.8	0.006	67	1.2 $\pm$ 1.9	6	1.3 $\pm$ 2.2	0.94
Total training (h/week)	43	11.1 $\pm$ 5.9	21	13.4 $\pm$ 7.7	0.20	69	10.2 $\pm$ 5.0	6	12.1 $\pm$ 6.5	0.38

At the time of inclusion, male athletes who went on to develop jumper's knee had significantly better results in CMJ compared to asymptomatic males, while no difference was detected in SJ (table 2). For females, there was no difference in SJ or CMJ at inclusion (table 2). In a multivariate logistic regression analysis corrected for gender and previous volleyball training, the OR for developing jumper's knee was 2.09 (95% CI 1.03 to 4.25) per cm difference in CMJ at the time of inclusion. A



logistic regression analysis for males corrected for previous volleyball training only gave an OR 1.79 (95% CI 0.96 to 3.35).

Table 2. Jumping ability at inclusion and change ( $\Delta$ ) in jumping ability during the study period. Data are shown as the average with SD or 95% confidence intervals (CI) as noted.

	Healthy				Jumper's knee				p-values between groups		
	N	Inclusion (mean $\pm$ SD)	$\Delta$ (95% CI) 6 months	$\Delta$ (95% CI) Total	N	Inclusion (mean $\pm$ SD)	$\Delta$ (95% CI) 6 months	$\Delta$ (95% CI) Total	Inclusion	$\Delta$ 6 months	$\Delta$ Total
<i>Men</i>											
SJ	40	28.1 $\pm$ 6.1	3.8 (1.4, 6.1)	4.6 (2.6, 6.5)	22	30.3 $\pm$ 7.4	1.7 (-1.6, 5.1)	2.9 (-0.8, 6.6)	0.23	0.29	0.35
CMJ	44	34.6 $\pm$ 5.5	5.4 (3.7, 8.4)	6.5 (4.7, 8.4)	22	38.0 $\pm$ 5.8	3.5 (0.3, 6.7)	3.9 (0.2, 7.7)	0.03	0.24	0.15
<i>Women</i>											
SJ	67	21.7 $\pm$ 4.6	2.5 (0.9, 4.1)	2.6 (1.1, 4.0)	6	22.1 $\pm$ 3.2	2.1 (-11.7, 15.9)	-1.7 (-14.9, 11.5)	0.82	0.90	0.15
CMJ	57	24.8 $\pm$ 4.6	3.7 (2.4, 4.9)	2.8 (1.7, 3.9)	6	27.2 $\pm$ 5.4	1.7 (-6.4, 9.9)	-2.1 (-6.9, 2.7)	0.22	0.39	0.05

Table 2 also shows the change in jumping ability after 6 months and at the end of their period at school. Compared to baseline, healthy males and females improved their jumping ability in both tests after 6 months and at the end of their period at TVN. In the jumper's knee group, only males improved their CMJ results compared to baseline, while females did not improve. We could not detect a difference in the change in jumping ability between the jumper's knee group and healthy group, even if the jumper's knee group did more training during their time at TVN compared to those who remained asymptomatic (volleyball training: jumper's knee group  $14.4 \pm 2.5$  h/week (n=28) vs. healthy athletes  $11.8 \pm 2.7$  h/week (n=122),  $p=0.001$ , strength training:  $3.2 \pm 1.1$  vs.  $2.5 \pm 1.5$  h/week,  $p=0.04$ ).

Among athletes that remained healthy there was a weak correlation between the volume of volleyball training and change in jumping ability for CMJ from baseline until their last test at TVN ( $r^2=0.15$ ,  $p<0.001$ ). We found no correlation for SJ (last test) in this group, nor was there any correlation between training volume and change in jumping ability in the group of athletes who developed jumper's knee.

## ***Discussion***

Our main finding was that baseline jumping ability was a risk factor for developing jumper's knee. Boys that later went on to developing jumper's knee jumped higher in a CMJ test at the time of inclusion compared to those who remained asymptomatic. An obvious explanation for this finding could be that players who jump well subject their tendons to higher load and therefore have higher risk. We only found this difference in the dynamic CMJ test, not in the more static SJ. It may be that these athletes are better at utilizing the eccentric prestretch component of the ballistic motion to increase their jumping height. It should be noted that our findings mirror those of a previous case-control study in senior elite volleyball players, where a substantial difference in CMJ (5.9 cm) was seen in favour of players with established jumper's knee (n=12) compared to an asymptomatic control group (n=12), while there was no difference in SJ.[14] It should also be noted that these differences were less pronounced when asymptomatic and symptomatic players were compared in a larger cross-sectional study (n=47).[15] Nevertheless, the current study is the first to assess jump performance

before players go on to develop symptoms of jumper's knee and our findings support the hypothesis that there is an association between the talent for jumping high and the risk for developing jumper's knee.

Similar observations, indicating a relationship between physical performance and injury risk, have been reported from other sports. Pitchers with a talent for high-velocity throwing are attractive, but the fastest throwers also seem to have an increased risk of overuse injuries to the shoulder and elbow.[21-24] They also pitched more months per year, games per year and pitches per game.[21] In an Australian cricket cohort, players had significantly increased risk of injury if they completed more than 75 throws/week.[25] These findings are similar to our observations on the same volleyball cohort, where we have shown that training and competition volume are important risk factors.[12] Ideally, we would have wanted to include performance (jumping ability) and exposure (training and competition volume) in one multivariate model, as it appears likely that they may be correlated. Unfortunately, this was not possible, as we do not have data on training and match exposure for the full 5-year period. For acute injuries, a relationship has been observed between running speed and increased risk of hamstring injuries in Australian rules football and risk of groin injury in Norwegian football.[26,27]

Another hypothesis was that not only baseline jumping ability, but also the rate of improvement in jumping ability could be a risk factor, i.e. that players who increase their jumping ability rapidly would be at higher risk because their capacity for loading the tendon is not matched by a simultaneous improvement in tendon properties. Our results did not reveal any significant differences in the change in jumping ability between the group that developed jumper's knee and those who remained asymptomatic, although both groups improved their CMJ performance. The exception was the few girls that developed jumper's knee, where we even observed a decrease in their jumping performance for CMJ. The jump tests were performed at the time of inclusion and then every 6 months until they finished school. The mean time until symptom onset was less than one year, and even within the first 6 months many had developed jumper's knee. One possible explanation is therefore that players who developed jumper's knee were unable to benefit maximally from the TVN program and may even have been limited by pain during testing.

Early sport specialization is a contentious issue.[28-31] One question is whether varied sports participation during adolescence can protect against overuse injuries. Repetitive volleyball-specific training alone could overload the patellar tendon, in contrast to a more varied training program which includes other sports. Our data show that boys in the jumper's knee group hardly played any other sports during the final year before joining the intensive volleyball program at TVN (mean 0.3 h/week out of 13.4 h/week of total training during the previous year). We have previously published similar findings in a slightly smaller sample from the same cohort.[12] However, although statistically significant, the difference when comparing with the healthy group was small (1.5 out of 11.1 h/week total training) and we do not know their training history during preceding years. More data is needed to investigate the relationship between early specialization in sports and injury risk.

We have used a clinical diagnosis of jumper's knee as the outcome in this study. This may be a limitation, as symptoms typically increase slowly and there is no clear cut-off for when to diagnose. Our definition required that the athlete considered the symptoms sufficient to represent a substantial problem for him/her. Some did not even inform the school physiotherapist about their problem, for fear of being sidelined and possibly also because they knew that no "easy fix" was available for the condition. Therefore, the principal investigator examined all athletes twice yearly, and the mean VISA score was 72 points after diagnosis. This means that their symptoms were moderate, similar to scores reported by adult, elite volleyball players with jumper's knee,[20] in the high range of patients enrolled in non-operative clinical trials,[19,32] and much less severe than patients considered as candidates for surgery (VISA score ranging from 30 to 50 points).[32-34] However, we do not know if all symptomatic athletes also had structural tendon changes, as ultrasound was not available from the start of this study.

Keeping these limitations in mind, this study still sheds light on what has been referred to as the jumper's knee paradox, that athletes with tendon pain have performed substantially better in jump tests compared to asymptomatic controls.[14-16] This is the first prospective cohort study available, where jump performance was assessed before players developed symptoms of jumper's knee, documenting an association between the jumping ability and the risk for developing jumper's knee. It seems

reasonable to suggest that their talent for jumping high, which results in higher tendon strain, amplifies the risk of tendon problems when subjected to an intensive program of training and competition such as that at TVN.

In baseball, safety recommendations have been developed for pitchers, limiting the number of pitches per game and number of months played per year from age 14 years through 20 years.[21] They also describe players with a higher risk of injury and recommend monitoring these closely for injury.[21] In volleyball, we currently do not have enough evidence to introduce “jump counts” for young athletes. In the present cohort we have identified gender, a high volume of training and match exposure and jumping ability as factors to identify players with a high risk for developing jumper’s knee. However, as vulnerability differs between players, more research is needed before we can individualize guidelines. In the meantime, the best advice we can give is to keep a close eye on the most talented players, where jumping ability is a key factor, to ensure that they are not overexposed to training and competition.

## ***Conclusion***

Volleyball players with a natural ability for jumping high has an increased risk of developing jumper’s knee. Boys who developed jumper’s knee jumped higher in a counter movement jump test at the time of inclusion compared to those who remained asymptomatic.

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**What this study adds:**

- Volleyball players with a natural ability for jumping high has an increased risk of developing jumper's knee.
- Boys who developed jumper's knee jumped higher in a counter movement jump test at the time of inclusion compared to those who remained asymptomatic.
- Early specialization in volleyball may be a risk factor for developing jumper's knee.



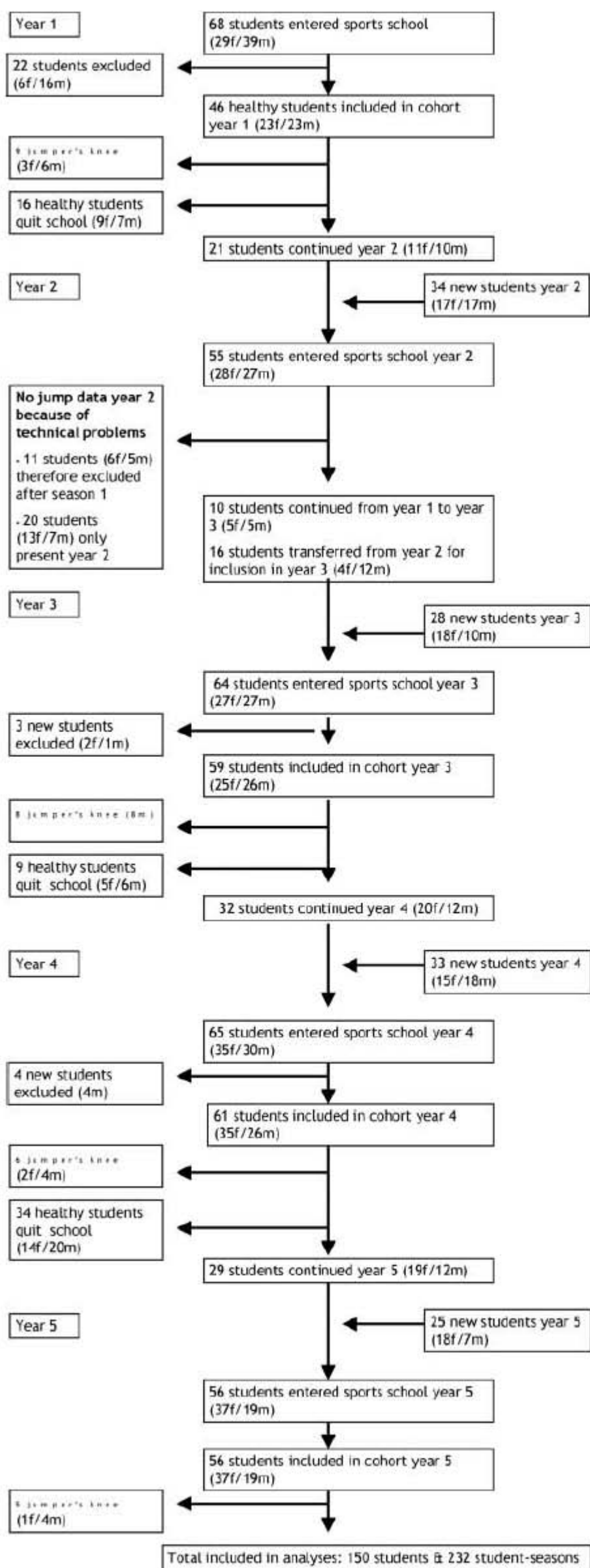
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Figure 1. Flowchart depicting the inclusion and follow-up of subjects during the 5-year study period.



**Figure 1** Flowchart depicting the inclusion and follow-up of subjects during the 5-year study period.