

Measures of Knee Capability in Handball Players Differ by Age: A Cross Sectional Study



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ABSTRACT

The return to sport after knee injury is challenging. This is burdensome for sports with a high incidence of injuries, such as team handball. Various tests guide decision making, but often the athlete's preinjury performance of these measures remains unknown. Moreover, objective return-to-sport criteria of a matching population are missing. The purpose of this study was to evaluate objective measures of knee capability in handball depending on players' age. Two hundred sixty-one handball players performed a functional test battery designed to evaluate knee capability after an anterior cruciate ligament injury: two- and one-legged stability analysis, jumps, speed tests, and agility assessments. For age-specific evaluation, athletes were divided into three age groups (16–19; 20–29; ≥ 30 years). Male players showed differences in two and one-legged jumping height ($p < 0.02$) as well as power per body weight ($p < 0.01$) between age groups. Young female players reached better results in two- and one-legged stability. Besides the quick feet test, results of females did not differ between age groups. Functional knee stability in healthy handball players is partly influenced by age, and females show better results in stability and male athletes in power measurements. This aspect should be considered for return to sports testing and underlines the importance of performance measures in athletic testing.

Introduction

Handball is a high intensity pivoting team sport that is rapidly growing in popularity and media attention all over the world. It is characterized by intense body contact, high running speed and quick

changes of direction. Despite the growing global interest of sports medicine and science in handball, athletes are often affected by injuries [1, 2]. In the last four summer Olympic Games, handball was even one of the sports with the highest risk of injury [3]. Several

surveys examined the relationship between age and injury incidence in handball, but results are contradictory [4, 5]. For example, Luig et al. detected the highest risk of injury for players aged 25–34 (up to 87.3% injured players during season) and the lowest risk of injury for players < 20 (56% injured players during season) [6].

Regardless of age, the knee is the most severely injured joint (up to 35%) and the anterior cruciate ligament (ACL) the most frequently injured structure of the knee [7]. In addition, Muller et al. recently found the age of the patient as one of five independent factors for the return to preinjury sports after ACL injury [8].

Previously known risk factors of non-contact ACL injury are either determined, such as sex, genetic predisposition, and width of intracondylar notch, or extrinsic (sport, underground, shoes, training intensity, and level of competition) [9–12]. Most recently, interventional and biomechanical studies found the knee abduction angle during landing, trunk displacement, or power development during lift-off in a countermovement jump to be correlated with non-contact ACL injuries and helpful in prevention [13–18]. In consequence, athletes' neuromuscular control, as an intrinsic mutable risk factor, is a key factor to prevent such serious knee injury. Reasonable test and measures therefore involve tasks in jumping [18], landing [13], side-cutting [19, 20] and balance [21, 22] and are summarized as “functional knee stability” [23]. Unfortunately, scientific studies measuring functional knee stability in an objective manner in handball are lacking [24, 25]. Moreover, most of the recent studies in handball examined professional players in national teams or elite divisions of the respective country. Since athletes in higher divisions have a higher level of physical fitness [26, 27], a transfer of their results to non-professionals is only possible to a limited extent. However, the majority of handball players are non-professional athletes and remain unrepresented so far.

The aim of the present study was to evaluate functional knee stability in non-elite handball with respect to players' age based on an established test battery to identify the major risk factors of neuromuscular control as a possible link to the high rate of knee injuries in team handball. It was assumed that knee function differs related to age. Secondly, collected data of this study should provide the basis for a first objective reference set to interpret the functional knee stability in non-elite handball, used to identify athletes' deficits to prevent (re-)injuries and to facilitate the decision for return to sports (RTS) in an amateur athlete.

Material And Methods

Subjects

A total of 261 non-elite handball players (female $n = 130$; male $n = 131$) with a mean age of 25.1 ± 5.8 years were recruited. Participants had to be at least 16 years of age and free of injury for at least six months before participation. Individuals with pain in the lower limbs were excluded. All subjects completed a 24-item questionnaire including demographic data as well as handball-specific characteristics (e.g., league, handball experience, training load). After testing, participants were divided into three groups according to their age:

- Young athletes (AG1: 16–19 years; female/male: 12/28; mean age: 18.0 ± 0.9 years)

- Middle-aged athletes (AG2 20–29 years; female/male: 97/68; mean age: 24.0 ± 2.9 years)
- Elderly athletes (AG3: over 30 years; female/male: 21/35; mean age: 33.5 ± 4.5 years)

Anthropometrics and handball-specific characteristics of the players in the respective age groups are summarized in ► **Table 1**.

Knee injury was defined as an injury caused by handball (game or training) and leading to a training and/or competition absence of at least one week. A history of previous knee injury or pain was reported by 36.8% of the subjects. Before completing the test protocol, participants or their legal representatives provided written consent as approved by the Ethics Committee of the local university (18–8078-BO) in accordance with the Declaration of Helsinki. To ensure the same conditions for all subjects, data was collected during the pre-season of all handball teams (June–August). In this period, all athletes participated in a regular light resistance training for upper and lower limbs twice a week.

Test battery

For assessment of functional knee stability, athletes completed the Back in Action performance test battery (BiA) [28, 29]. These functional tests include:

- stability analysis: two-legged (TL-ST) and one-legged (OL-ST),
- countermovement jumps: two-legged (TL-CMJ) and one-legged (OL-CMJ),
- plyometric jumps: two-legged (TL-PJ),
- speedy jumps: one-legged (OL-SJ),
- quick feet test (QF).

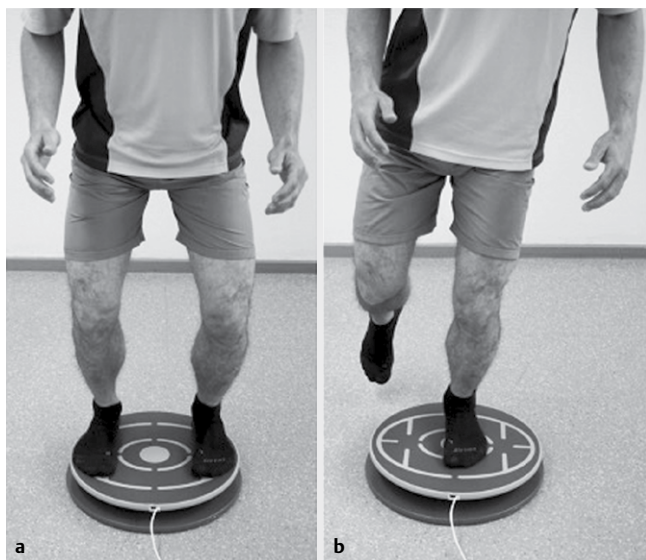
The test elements are described in detail in the following sections.

The stability analysis (TL-ST and OL-ST) was performed on a freely moveable MFT Challenge Disc (TST Trendsport, Grosshöflein, Austria) connected to a computer. The PC screen provided visual feedback during balancing on the disc. For two-legged stability, athletes were asked to stand on both legs with slightly bent knees in the center of the disc and keep their balance for 20 seconds (► **Fig. 1a**). The level of stability was measured (Balance Index Scale (BIS): 1 pt., best score; 5 pts., worst score). The one-legged stability test was performed identically to the two-legged stability test but had to be performed one-legged (► **Fig. 1b**). The one-legged stability test was initiated with the dominant leg, followed by the non-dominant leg [28, 29].

The jump tests were performed using the Myotest sensor (Myotest S.A., Sion, Switzerland). The sensor was fixed to the player's pelvis with the help of a belt. Before performing the test, the athlete had to stand still in an upright position with arms placed on the hips. In this initial position, the Myotest sensor determined a baseline to calculate the maximum jump height (cm), relative power per body weight (W/kg), and ground contact time (ms). To perform the two-legged countermovement jumps (TL-CMJ), athletes were asked to bend their knees and jump as high as possible. The test was performed without an arm swing, and hands were kept on the waist throughout the jumping process (► **Fig. 2a**). The one-legged test was executed the same way as the TL-CMJ test (► **Fig. 2b**). The test was initiated with the dominant leg, followed by the non-dominant leg.

► **Table 1** Descriptive analysis (mean and SDs) and p-value of anthropometrics and handball-specific characteristics regarding athlete's age (AG1 16–19 years; AG2 20–29 years; AG3 over 30 years) for n = 261. The p-values describe significant differences between age groups. F, female; M, male.

	AG1 (F/M:12/28)	AG2 (F/M: 97/68)	AG3 (F/M: 21/35)	p-value
Body height (cm)	179.3±8.3	176.6±9.5	179.0±9.5	0.107
	F169±4.6	F 170.1±6.3	F 171.0±6.8	0.667
	M 183.8±4.9	M185.2±6.2	M 183.7±7.5	0.443
Body weight (kg)	76.8±12.1	78.4±14.0	84.0±12.3	0.011
	F65.5±9.7	F 71.1±11.3	F 76.2±11.4	0.029
	M 81.6±9.7	M88.8±10.6	M 88.7±10.4	0.006
BMI (kg/m ²)	23.5±2.7	24.8±3.2	25.9±2.9	0.001
	F22.7±3.4	F 24.3±3.2	F 25.7±4.0	0.047
	M 23.8±2.3	M 25.4±3.2	M 26.0±2.1	0.006
Handball experience (years)	10.5±2.6	14.3±4.8	22.9±6.2	0.000
	F10.0±3.2	F 14.2±5.0	F 21.2±4.6	0.000
	M 10.7±2.4	M 14.5±4.6	M 23.8±6.9	0.000
Training load (hours/week)	7.6±3.4	5.9±2.1	5.8±2.3	0.000
	F 7.8±4.2	F5.5±1.8	F 5.6±2.1	0.003
	M 7.4±3.1	M 6.4±2.5	M 5.9±2.5	0.077
Played matches (last season)	24.5±10.5	18.6±8.5	17.4±9.3	0.000
	F 25.0±10.3	F 19.7±7.5	F 17.1±7.3	0.021
	M 24.3±10.8	M 17.1±9.6	M 17.6±10.5	0.007
Number of knee injuries	0.4±0.7	0.8±1.1	1.3±1.8	0.001
	F 0.3±0.5	F 0.8±1.1	F 1.7±1.8	0.002
	M 0.4±0.7	M 0.6±0.9	M 1.0±1.8	0.073



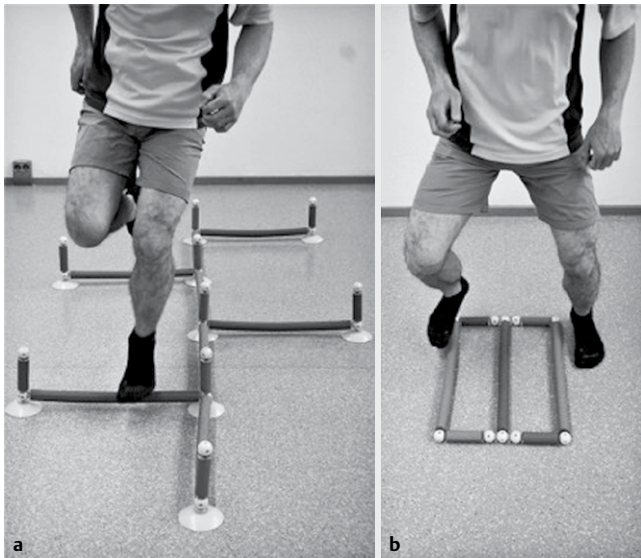
► **Fig. 1** Performing the stability tests of the Back in Action test on the MFT disc. **a)** The two-legged stability test (TL-ST). **b)** The one-legged stability test (OL-ST).

For the two-legged plyometric jumps (TL-PJ), athletes were asked to perform four consecutive jumps as high as possible. For minimal ground contact time, they were instructed to rebound explosively between the jumps. The arms had to be placed on the hips throughout the entire test.



► **Fig. 2** Performing the jump tests of the Back in Action test. **a)** The two-legged countermovement jump (TL-CMJ) test. **b)** The one-legged countermovement jump (OL-CMJ) test.

To test the one-legged speedy jumps (OL-SJ), the Speedy Basic Jump Set (TST Trendsport, Grosshöflein, Austria) was used. The athletes were instructed to complete 16 one-legged jumps through a



► **Fig. 3** Performing the speed and agility tests of the Back in Action test. **a)** The one-legged speedy jump (OL-SJ) test. **b)** The quick feet (QF) test.

coordination course of red (forward-backward-forward jumps) and blue (sideway jumps) hurdles as fast as possible, and time was recorded (► **Fig. 3a**). As in the previous one-legged measurements, the dominant and the non-dominant legs were tested.

For the quick feet test, the Speedy Basic Jump Set was also used. The participants were instructed to step in and out of a box for 15 times as quickly as possible (► **Fig. 3b**). Timekeeping started when one foot hit the center of the box and ended when both feet were outside.

Statistical analysis

Statistical analysis was performed using SPSS (V25 for mac; IBM Corp., Armonk, NY, USA). Mean values and standard deviations (SDs) are presented for dependent variables. To test for normal distribution of the variables, the Kolmogorov–Smirnov test was used. Differences between age groups were tested either with an analysis of variance (ANOVA) or with the Kruskal–Wallis test. The pairwise analyses to identify differences between the variables were made using the unpaired t-test or the Mann–Whitney U test. After a Bonferroni correction for multiple comparisons was applied, the level of significance was set at $p < 0.05$.

Results

The Back in Action test results of the 261 non-elite athletes of different age groups revealed significant differences in functional knee stability. Related data is presented for all, and the females (F) and the males (M) for each age group separately (► **Table 2**).

Besides the comparable results of the speedy jumps and quick feet tests, significant group differences were detected in all performance tests for stability and strength measures.

With respect to stability, group differences could be detected in both the two-legged and one-legged stability analyses. Signifi-

cant differences in the TL-ST could be shown between players of AG2 and AG3 ($p = 0.01$) for the cohort of athletes. Here, young players exhibited lower balance scores than elderly players, reflecting superior balance. Significant group differences were also present in the OL-ST of the dominant leg between AG2 and AG3. Here, young athletes presented lower balance scores than the elderly ($p = 0.01$). In summary, the lowest balance scores overall were demonstrated by female athletes of AG1, while female and male players of AG3 achieved the highest balance scores (worst balance).

Regarding strength, significant differences were shown in all jump tests (► **Fig. 4**). In the two-legged countermovement jumps, females and males of the AG1 jumped significantly higher than athletes of the AG2 as well as AG3, and male athletes developed significantly more power than players in the AG2 or AG3. With respect to the one-legged countermovement jump, males of AG1 jumped significantly higher than players of AG2 or AG3 in the dominant and the non-dominant leg, which was also significant for the entire population. In addition, participants of AG1 reached significantly more power in the OL-CMJ of the non-dominant leg than participants of the AG2 ($p = 0.01$). In the jump height of the two-legged plyometric jumps, individuals of the AG1 performed higher jumps than individuals of the AG2 ($p < 0.01$) and AG3 ($p < 0.03$) with ground contact times being comparable.

Means, standard deviations (mean \pm SD) and significant differences of age groups of both sexes regarding anthropometrics (► **Table 1**) and functional performance tests (► **Table 2**) are presented in tables.

Discussion

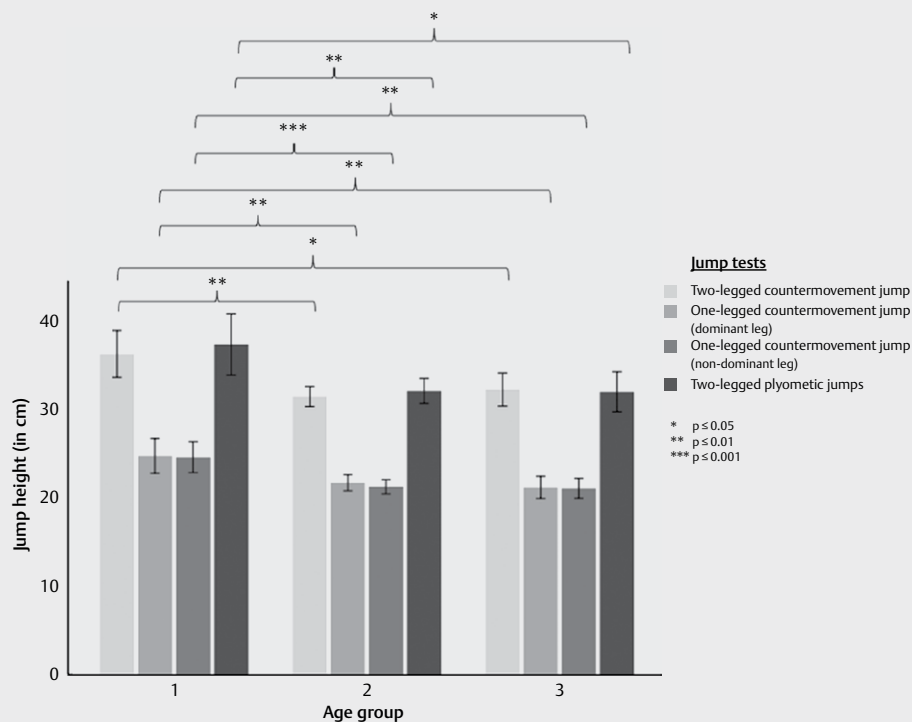
This cross-sectional study was designed to evaluate the functional knee stability (jumping, landing, cutting, balance) of handball players regarding age and sex using an established test battery giving objective metric measures. Overall, the cohort of athletes of AG1 performed significantly better in stability and strength compared to older athletes. This may lead to premature conclusions regarding the functional knee stability and injury risk of older athletes. Nevertheless, female and male handball players showed relevant difference in the results of the Back in Action test and therefore, to study the effect of age alone, both sexes have to be evaluated separately.

Surprisingly, previous studies on differences in injury incidence regarding age groups showed contradictory results. In 2014, Monaco et al. [4] analyzed injuries of 496 elite male handball players of different ages over five seasons. Here, no statistically significant differences between the groups were found despite differences in age. In contrast, Tabben et al. [5] conducted a study during the Men's Handball World Championship 2017 in France with 387 players and detected a higher risk of match injuries for elderly players compared with their younger team colleagues.

Female athletes, on the other hand, are known to be at high risk for first-time non-contact ACL injury owing to several reasons [30], especially increased dynamic valgus and high abduction loads [17] approx. 40 milliseconds after initial contact of landing [20], and hormonal changes during the preovulatory phase [31]. For the summer Olympic games in London, handball was one of the most injury-causing disciplines (5%), with women sustaining injuries

► **Table 2** Descriptive analysis (mean and SDs) and p-value of the Back in Action performance tests regarding athlete's age (AG1 16–19 years; AG2 20–29 years; AG3 over 30 years) for n = 261. The p-values describe significant differences between the groups. F, female; M, male.

	AG1 (F/M:12/28)	AG2 (F:M: 97/68)	AG3 (F/M: 21/35)	p-value
Leg Stability (score)				
Two-legged	3.9±0.6	3.8±0.7	4.0±0.8	0.018
	F 3.2±0.4	F 3.4±0.7	F 3.6±0.8	0.247
	M 4.2±0.3	M 4.3±0.4	M 4.3±0.6	0.541
One-legged				
Dominant leg	3.9±0.7	3.7±0.7	4.0±0.6	0.009
	F 3.2±0.5	F 3.4±0.7	F 3.6±0.8	0.340
	M 4.2±0.5	M 4.0±0.5	M 4.2±0.4	0.129
Non-dominant leg	3.7±0.7	3.7±0.6	3.9±0.6	0.052
	F 3.1±0.6	F 3.4±0.6	F 3.4±0.6	0.305
	M 4.0±0.5	M 4.0±0.5	M 4.2±0.4	0.138
Countermovement jumps				
Two-legged	36.2±8.2	31.5±7.4	32.6±6.8	0.001
Height (cm)	F 30.2±4.3	F 27.4±5.4	F 26.3±4.7	0.114
	M 38.7±8.2	M 36.7±6.5	M 35.1±5.7	0.112
Power (W/kg)	46.5±6.6	42.6±6.0	43.4±5.2	0.003
	F 41.4±4.1	F 39.3±4.8	F 38.6±4.0	0.237
	M 48.6±6.3	M 46.9±4.5	M 45.8±3.9	0.079
One-legged height (cm)				
Dominant leg	24.7±6.1	21.7±5.9	21.1±4.6	0.003
	F 19.0±2.9	F 18.7±4.0	F 17.9±2.9	0.634
	M 27.1±5.5	M 25.6±5.6	M 22.8±4.4	0.005
Non-dominant leg	24.5±5.5	21.3±5.2	20.1±4.1	0.002
	F 19.8±2.3	F 18.9±4.0	F 17.8±4.8	0.358
	M 26.5±5.2	M 24.2±5.3	M 22.5±3.1	0.005
One-legged power (W/kg)				
Dominant leg	37.0±5.7	35.0±5.2	35.3±3.9	0.073
	F 31.0±3.7	F 31.8±3.5	F 31.7±2.8	0.676
	M 39.5±4.3	M 39.2±3.9	M 37.2±3.1	0.031
Non-dominant leg	37.1±5.0	34.6±4.8	35.0±4.9	0.009
	F 31.7±3.2	F 31.9±3.8	F 31.6±4.7	0.947
	M 39.3±3.8	M 38.2±3.6	M 36.6±2.7	0.007
Plyometric jumps				
Height (cm)	37.2±10.9	32.1±9.3	31.9±8.2	0.007
	F 32.1±3.3	F 28.4±8.3	F 26.2±6.2	0.122
	M 39.5±12.2	M 37.0±8.0	M 35.1±7.5	0.164
Ground contact time (ms)	249.9±104.7	221.3±86.0	239.0±99.1	0.232
	F 188.0±48.9	F 219.8±91.7	F 204.4±80.8	0.427
	M 276.5±111.5	M 221.2±76.8	M 257.1±102.8	0.026
Speedy jumps (s)				
Dominant leg	7.4±2.4	7.7±2.1	7.9±3.4	0.486
	F 7.4±0.7	F 8.2±2.4	F 9.2±3.8	0.117
	M 7.4±2.9	M 7.1±1.4	M 7.0±1.1	0.568
Non-dominant leg	7.4±3.2	7.7±2.0	7.9±3.4	0.162
	F 7.4±1.3	F 8.2±2.4	F 9.8±5.0	0.066
	M 7.4±3.8	M 7.2±1.5	M 7.0±1.1	0.760
Quick Feet (s)	8.8±1.1	9.3±1.4	9.3±1.3	0.089
	F 8.6±1.2	F 9.5±1.2	F 9.9±1.4	0.016
	M 8.8±1.0	M 8.9±1.5	M 9.1±1.3	0.792



► **Fig. 4** Results of the jump performance of the Back in Action test with respect to players' age for n = 261. Female and male athletes.

more frequently than the men. In addition to the investigations mentioned above, differences in various athletic skills regarding age could be detected in the current study, which are outlined below.

Age and balance measures

Balance analysis revealed that male and female performance of different age groups does not differ by age but by sex. Whereas males show worse balance scores compared to women in all categories, females of AG1 present the best results in TL-ST and OL-ST. It is worth mentioning that results of the non-dominant leg, most often used for landing after a jump shot, were even superior. Still, level of stability was lower when data was compared to the reference population of both sexes published by Hildebrandt (TL-ST: 2.60 ± 0.47) [32]. As separately presented data for males and females does not change significantly, an effect of age on one-legged or two-legged stability was not proven. Within this context, training of neuromuscular stability has proven to improve dynamic balance but not static balance in an interventional program [33]. Similar programs have been shown to reduce ACL injury risk for female team handball players [15] and for a population of both sexes [34]. Moreover, a prospective study in Norway by Steffen found no association between postural control and ACL injury in 838 cases of female handball and football players [35]. Therefore, the significance of postural control and its testing in handball remains a matter of debate and needs further scientific attention.

Age and complex task measures

Speedy jump test and quick feet test results were on the same level, and therefore a general impaired physical fitness of older athletes (AG3) in comparison to young athletes (AG1) was not found, even when both sexes were analyzed separately. Without reaching a significant level, male athletes trended toward improvement in the speedy jumps, while female athletes showed slower times with increasing age. It is noteworthy that all noted times of the complex measures were slower than reference data of the test battery [32]. Moreover, results of female age groups were not significantly different in stability measures but in the quick feet test. More complex functional testing may therefore be sensitive to illustrate differences in such settings. This is in line with studies on trunk control [16], backward landing [36], or vertical jump kinetics [18].

Age and strength measures

Results of the strength-related test items mirror these findings: While female athletes reflect similar measures (with only non-significant changes), male athletes present with alterations in power (W/kg body weight) and jump height in the one-legged test. A decrease in whole body muscle mass with age may possibly account for these observations [37].

On the other hand, in comparison to data of 42 elite handball players reported by Wagner et al. [38], jumping performance of all athletes barely differed, while Wagner's participants were semiprofessional. In a study by Granados et al. [26], female elite (EP) and amateur players (AP) were compared by age (EP: 23.5y avg.; AP: 21.4y avg.). These subjects are comparable to female AG2 of the current study.

Presented data on jump height (EP: 34.9 ± 5 cm and AP: 33.0 ± 3 cm) is higher than heights reached by females in our study. It is notable that because data between elite and amateur players did not differ significantly, Granados went on to conclude that the differences in the fat-free body mass alone could account for the differences between the groups. Similarly, body weight and BMI are higher in older age groups in this study as well, although fat-free body mass was not measured. This trend was also noticed by Wagner, starting at the age of U15, U17, U19 and U23 aged elite athletes in Austria [38].

The subject of leg symmetry measurements in pre-injured athletes is controversial. This population has not shown relevant limb symmetry differences in the CMJ or the speedy jumps, whereas elite athletes in snowboarding [39] or judo and Taekwondo were seen with up to 25% of athletes under 90% symmetry [40]. For handball players on an elite level, no differences in limb symmetry were found when normalized for body mass [41] and is comparable to a “normal population” regarding limb symmetry [42]. Rehabilitation research has even shown significant limb differences in athletes 9 months post ACL injury [43] as well as in athletes with prior ACL injury [44] and is consequently associated with impaired performance in a return-to-sport testing [45].

In comparison to the power calculation of the CMJ, age-related measure of peak torque (Nm) for isokinetic knee extension showed parallel results in a study on healthy subjects by Harbo [46]. Neder et al. [47] evaluated 96 non-sportive subjects between 20–80 years in an isokinetic setting with a leg extensor. They found an inverse relationship of age and power starting at the age of 20 in their regression model. Similarly, non-elite male athletes in this study showed significant decreases in W/kg between AG2 (24.0 ± 2.9 y) and AG3 (33.5 ± 4.5 y). They concluded that the main factors of prediction were sex and age, although only few differences in strength exist when normalized for active muscle. Lindle et al. [48] found similar courses of concentric and eccentric power of the knee extensors, although their regression model did not reveal the drop of peak torque power to become significant before the age of 35 to 40 years. Borges [49] controversially reported a significant decrease for males between the age of 20 and 30 years, which may partly account for the differing results of AG1 and AG2.

In addition, the difference in training frequency of the respective age groups in our study might be a confounder. Young athletes (16–19 years) spent significantly more time (1.7 ± 1.2 hours) for handball training than older handball players. This difference in physical activity is known to interact with age differences [50]. This may lead to impaired physical fitness, possibly resulting in later injury.

Similar findings were recently reported by Szyski [51] for soccer players of different leagues but also for handball players of different leagues [52].

Overall, results of male and female athletes were inferior to the initial data set given by Hildebrandt [29], which raises concerns regarding the physical fitness and injury risk of these amateur handball players.

Consequently, the implementation of a prevention program is the next step, such as the FIFA 11+, which has shown promising results in male athletes [53]. Unfortunately, results differ for similar programs in female populations [54]. Various freely accessible prevention programs are available, which may be adapted depending on the specific sport discipline [23].

This study has some limitations. First, the main methodological limitation of this study is the limited sample size. The number of 261 subjects was constrained by the size of the handball teams. To obtain more detailed information about functional knee stability in handball, further studies of handball players are required. Additionally, this study was cross-sectional with one timepoint of measurement only. Further investigations including interventions and prospective study designs are necessary to prevent further injuries.

Summary

In summary, the present study is first to report differences in functional performance in relation to players' age and sex in handball. Results show stable levels of stability test in all three age groups and both sexes. Power measurements revealed a clear decrease of W/kg body weight for the male athletes as age increases, whereas female athletes maintain their level of performance. For the quick feet test, women decrease significantly with age. These findings demonstrate the importance of age-specific screening and prevention. Moreover, the present data set on the basis of an established test battery can be used as a first reference set for knee stability in non-elite handball including sport-specific reference data for non-professional athletes. This allows coaches to identify individual strengths and weaknesses to design training models to improve handball-specific performance and prevent injuries. Moreover, the reference data values of the present study may help to establish a new gold standard for (re-)injury prevention in a return-to-sport setting. Up to now, the comparison to the uninjured opposite leg is still common, although the uninjured knee may be deficient itself. The objective reference values of this study can facilitate the physicians' decision of a safe return to sports and help to set rehabilitation goals.

Conflict of Interest

The authors declare that they have no conflict of interest.

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