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Differences in Anthropometric Characteristics and Physical Capacities Between Junior and Adult Top-Level Handball Players

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Abstract

Background: In all age groups of handball players, anthropometric characteristics and physical capacities are important prerequisites to fulfilling the playing demands. However, there is no study that has compared anthropometric characteristics and physical capacities between junior and adult handball players by the same research design containing field tests.
Objectives: This study aimed to investigate differences in anthropometric characteristics and physical capacities between junior and adult top-level handball players using various field tests. Relationships among physical capacities were also examined.
Methods: Ten male junior (18 ± 1 years) and eleven adult (26 ± 1 years) field handball players competing in the U19 Bundesliga and DKB Handball-Bundesliga, respectively, were tested for body height, mass, fat, and fat-free mass as well as 30 m speed and 22 m change of direction (COD), squat jump (SJ) and counter movement jump (CMJ), one repetition maximum (1RM) bench press, core strength-endurance, and interval shuttle run test (ISRT). Magnitude-based inferences, effect sizes (ES), and Pearson correlation coefficients (r) were computed for statistical analyses.
Results: Juniors had a very likely lower body height, mass, and fat-free mass and likely lower 1RM bench press and ISRT performance (ES: 0.7 - 1.2). Contrary, juniors had a likely to very likely superior speed, COD, and SJ and most likely superior core strength-endurance performance (ES: 0.5 - 1.6). While speed, COD, and jump capacities were large to very large correlated in juniors (r = -0.55 - 0.86), they were mostly unclear correlated in adults (r = -0.05 - 0.79). Overall explained variance among speed, COD, and jump capacities was likely higher in juniors (51%) than adults (17%) (ES: 1.7).
Conclusions: This study shows that differences in anthropometric characteristics and physical capacities, and also in relationships among physical capacities, are evident between junior and adult top-level handball players, indicating different physical needs to play handball.

Keywords: Body Composition, Core Stability, Intermittent Endurance, Power, World Champion

1. Background

Handball is an intermittent high-intensity team sport played with body contact by six field players and one goalkeeper per team. The effective playing time is 2 × 30 minutes separated by a 10 min half-time break (1). During play, the players perform different types of activities, like runs (i.e., accelerations, decelerations, changes of direction, and sprints), jumps (i.e., throw jumps and blocks), ball throws (i.e., passes and shots), and duels (i.e., tackles, clasping, and screenings) (1, 2). Thereby, the external load is characterized by a total distance covered of 2.8 - 4.4 km (3, 4), mean velocity of 53 - 90 m/min (3, 5), sprinting distance of 78 - 107 m (3, 6), and peak velocity of 20 - 25 km/h (2), whereas the internal demand is considered by a mean heart rate of 82% - 83% (2, 3), peak lactate concentration of 3.7 - 9.7 mmol/L (7, 8), and fluid loss of 2.0 - 2.1 L (3, 8). Notably, all match play activities as well as external loads and internal demands differ not only according to playing positions (9), but also to offensive and defensive playing phases and tactical formations (1).

In handball, anthropometric characteristics as body height, weight, and composition (10, 11) as well as physical capacities like speed, change of direction (COD), power, strength, and intermittent endurance (12, 13) are important prerequisites to fulfill the playing demands in all age groups. Consequently, for competing on top-levels, it is essential to optimize anthropometric characteristics and physical capacities via training and testing procedures (1, 4). In this context, previous studies have focused on the body height, mass, fat, and fat-free mass (10, 14) as well as 30 m speed (12, 13) and COD (15, 16), squat jump (SJ) and counter movement jump (CMJ) (14, 17), one repetition maximum (1RM) bench press (18, 19), core strength-endurance (16, 17), and intermittent shuttle running (20, 21) performance of handball players from various backgrounds. While there exists many studies that have investigated such variables in adults (1, 4, 8, 10-12, 17-19, 21-23), there are less studies in juniors (3, 16, 20, 24, 25). Thus, more research in junior handball players is required.

However, there is only one study that has compared anthropometric characteristics and physical capacities between junior and adult handball players by the same research design (14), which is an essential methodological aspect, when aiming to describe differences between both age groups. It is worth noting that in this previous study, solely laboratory tests including sit-and-reach, jump height, handgrip strength, and cycling ergometer tests were conducted. Since laboratory tests have less validity concerning practical applications compared to field tests (26), a study also containing various field tests is required. In such a study, and similar to previous studies (22, 23, 27), it is further reasonable to examine relationships among speed, COD, and jump capacities to identify related or unrelated areas in both age groups. Such knowledge may help design different training and testing procedures for juniors and adults as well as assist in talent selection processes, especially when aiming to develop talented juniors toward prospective elite adult handball players (24).

2. Objectives

This study aimed to investigate differences in anthropometric characteristics and physical capacities between junior and adult top-level handball players using various field tests. Relationships among physical capacities were also examined.

3. Methods

3.1. Participants

Ten male junior (18 ± 1 years) and eleven adult (26 ± 1 years) top-level field handball players participated. While the juniors competed in the U19 Bundesliga, the adults played in the DKB Handball-Bundesliga and EHF European Cup. The juniors were placed fifth in the Bundesliga, whereas the adults were ranked second and won the EHF European Cup. Eight of the adults were also playing for their national teams. One of them had won the IHF World and three the EHF European Handball Championship. Over the entire season, the juniors performed five training sessions per week, whereas the adults trained on a daily basis and performed up to 10 sessions during the pre-season preparation. The players were familiar with all testing procedures as a part of their regular performance assessment program. The study was approved by the ethics committee of the local university.

3.2. Experimental Design

In our study, a cross-sectional descriptive-correlation experimental design was applied. All anthropometric and physical capacity tests were performed on one day during the pre-season preparation, where all players had attained a high-performance level. The tests were performed as previously described (28, 29) and were conducted in the following order: (a) anthropometric measures, (b) speed and COD tests, (c) SJ and CMJ tests, (d) a bench press test, (e) four different core strength-endurance tests, and (f) an intermittent shuttle running test. Before testing, the duration of the summer break and pre-season preparation as well as number of training sessions were approximately the same for juniors (i.e., six weeks, six weeks, and 36 sessions, respectively) and adults (i.e., four weeks, four weeks, and 40 sessions, respectively). The players were instructed to report to the tests well rested, to prepare themselves as they would for a competition, and to eat a carbohydrate-rich breakfast two hours before testing.

3.3. Anthropometric Measures

The body fat and fat-free mass of the players were predicted using a 4-point bioelectric impedance analysis (Bodystat, QuadScan 4000, Douglas, United Kingdom) in supine position under laboratory conditions. Thereafter, the players performed 15-minutes warming-up procedures that were conducted by the coaches and included different routine running, jumping, and functional mobilizing-strengthening activities. The players were given a 10-minutes recovery period between each of the following tests, which were performed along with the warming-up procedures in a sports hall.

3.4. Speed and Change of Direction Tests

For the speed test, the players started from a contact plate and sprinted over 30 m. Sprint times were recorded with timing gates (TDS Werthner Sport Consulting, Linz, Austria) at 5, 10, 20, and 30 m. For the COD test, the players started 1 m before the first timing gate (hs-electronics, Falkensee, Germany) and sprinted over 22 m including four changes in direction. The corresponding angles were 33, 95, 95, and 33°, respectively (Figure 1A). Both tests were repeated three times, separated by a 3-min recovery period, and the fastest sprints were used for statistical analyses.

3.5. Squat Jump and Counter Movement Jump Tests

For the SJ test, the players began in a squatting position at a knee angle of 90° and jumped upwards with the hands on their hips. For the CMJ test, the players started in a standing position at a knee angle of 180°, performed a downward movement, and jumped upwards with an arm swing. The jumps were performed on two separate force platforms (Kistler, 9286BA, Winterthur, Switzerland) and jump heights were calculated from ground reaction forces captured at 1,000 Hz through the impulse-momentum method. Both tests were repeated three times, separated by a 2-minutes rest period, and the highest jumps were used for statistical analyses.

3.6. Bench Press Test

For the bench press test, the players performed 3 - 5 submaximal to maximal bench press exercises using a 20-kg competition style bar (Gym80, International Sygnum Basic, Gelsenkirchen, Germany). After warming-up with individual weights, the weights were increased in 5-kg increments until a 1RM was reached. A trial was considered successful, when the players had lowered the bar downwards to their chest without bouncing and pushed the bar upwards until their arms were fully extended. After each trial, the players were given a 3-min recovery break and the realized 1RM was used for statistical analyses.

3.7. Core Strength-Endurance Tests

For the core strength-endurance tests, the players performed four separate tests (i.e., a ventral, lateral-left, lateral-right, and dorsal test) (Figure 1B - D) as described in detail elsewhere (29). Briefly, the tests consisted of repeated concentric-eccentric exercises over defined movement ranges. Movement velocities were dictated by a metronome (KORG KDM-1, Inage, Japan) at 1 Hz and times to failures were measured next to one second with a stopwatch. The tests were stopped, when the players failed to perform the entire movement ranges or were unable to follow the dictated velocity. The players were given a 5-min recovery period between each test. The sum of times achieved during all four tests was used for statistical analyses (29).

3.8. Intermittent Shuttle Running Test

Finally, for the intermittent endurance test, the players performed an interval shuttle run test (ISRT) (28). Thereby, the players ran 20 m shuttles at progressively increasing velocities controlled by audio signals from a computer. The protocol consisted of alternating running and walking periods for 30 and 15 seconds, respectively. The test was terminated, when the players could not follow the velocity during two consecutive shuttles. To clarify whether exertion was reached, the players were equipped with chest-belts (Suunto, t6, Vantaa, Finland) and required to reach > 95% of their predicted maximum heart rate (220-age), which was met in all players. The number of shuttles completed was used for statistical analyses.

3.9. Statistical Analyses

Descriptive data are reported in means and 90% confidence intervals (CIs). To investigate differences between both age groups, a progressive statistical approach, namely magnitude-based inferences, for practical importance was applied (30). Therefore, the dispositions of the CIs for the mean differences in relation to the smallest worthwhile differences (SWDs; i.e., the pooled standard deviation multiplied by 0.2) were analyzed. Then, the likelihoods for juniors having "true" higher, similar, or lower values than adults were determined and qualitatively described using the following probabilistic scale: < 1%, most unlikely; 1 to < 5%, very unlikely; 5 to < 25%, unlikely; 25 to < 75%, possibly; 75 to < 95%, likely; 95 to < 99%, very likely, and ≥ 99%, most likely. If the likelihoods for having both higher and lower values were ≥ 5%, the differences were described as unclear. Otherwise, the differences were interpreted according to the observed likelihoods, whereas only those differences rated as at least likely (i.e., ≥ 75%) were considered. To clarify the meaningfulness of the differences, effect sizes (ESs) according to Cohen's d were calculated and interpreted accordingly: 0.2 to < 0.6, small; 0.6 to < 1.2, medium; 1.2 to < 2.0, large; 2.0 to < 4.0, very large; and ≥ 4.0, extremely large (30). To determine relationships among speed, COD, and jump capacities, Pearson correlation coefficients (r) and 90% CIs were computed and described as follows: < 0.1, trivial; 0.1 to < 0.3, small; 0.3 to < 0.5, moderate; 0.5 to < 0.7, large; 0.7 to < 0.9, very large; and ≥ 0.9, extremely large. If the CIs overlapped zero, the correlations were considered as unclear (30). To compare correlations between both age groups, common variances from coefficients of determinations (R^2) were calculated and expressed as factors. The single factors, and also the mean factor (i.e., the overall explained variance), among speed, COD, and jump capacities were compared between both age groups through magnitude-based inferences likewise. Therefore, the smallest worthwhile ratio (SWR) of the factors was consistently defined as 1.1 (i.e., a common variance of 10%) (30). While the magnitude-based inferences were determined using the spreadsheets available at http://www.sportsci.org/, all other statistics were

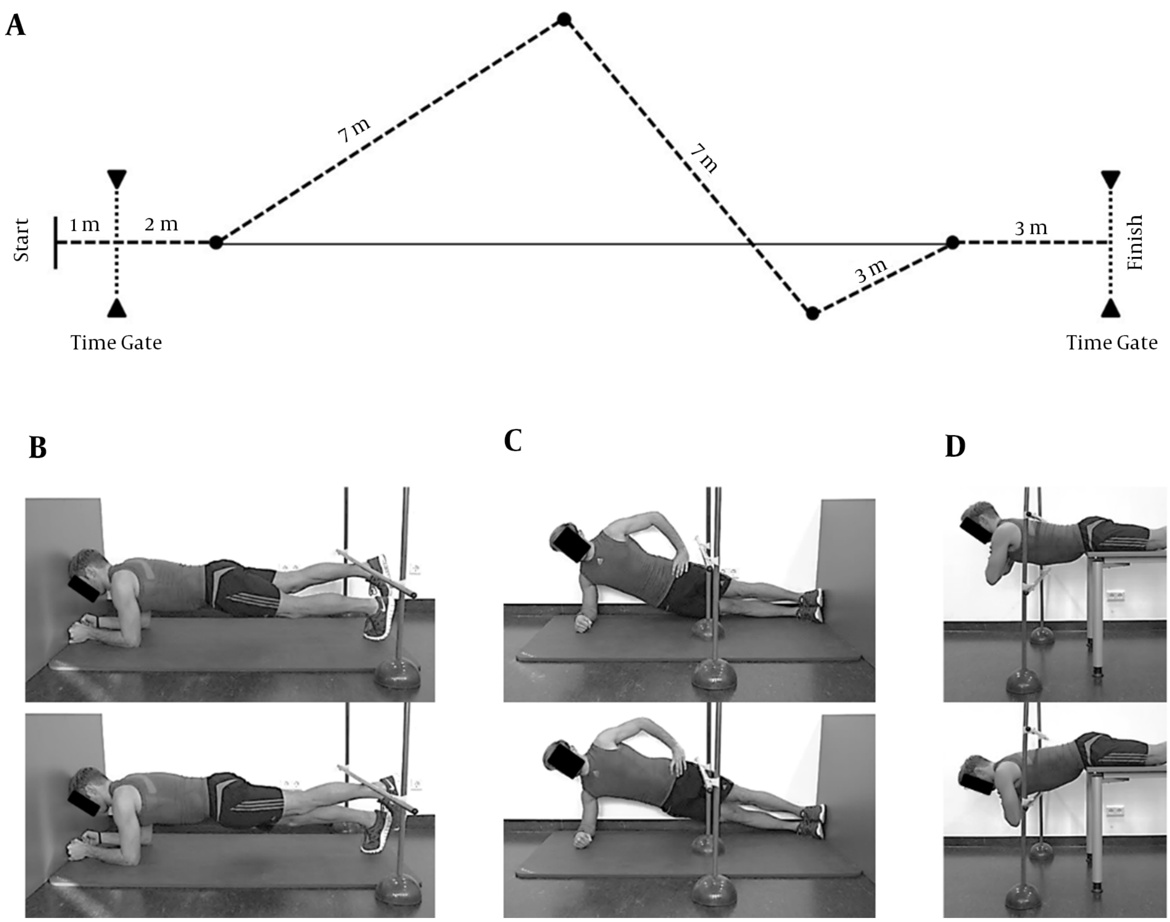


Figure 1. Design of the Change of Direction (A) as well as Ventral (B), Lateral (C), and Dorsal (D) Core Strength-Endurance Test

computed using the SPSS software package (IBM, Version 22, New York, USA).

4. Results

4.1. Differences

Table 1 shows that juniors had a likely to most likely lower age, handball experience, body height, mass, mass index, and fat-free mass (ES: 0.7 - 1.2) as well as likely lower 1RM bench press and ISRT performance (ES: both 0.7) than adults. Contrarily, juniors had a likely to very likely superior speed, COD, and vertical SJ (ES: 0.5 - 1.3) and most likely superior core strength-endurance performance (ES: 1.6). No further differences rated as at least likely were found.

4.2. Relationships and Explained Variances

Table 2 shows that speed, COD, and jump capacities were large to very large correlated in juniors (r = -0.55 - 0.86), whereas they were mostly unclear correlated in adults (r = -0.05 - 0.79). With exception among COD as well as SJ and CMJ performances, likely to most likely more common variances among speed, COD, and jump capacities could be explained in juniors than adults.

Figure 2 shows that the overall explained variance among speed, COD, and jump capacities was likely to be higher in juniors (51%) than adults (17%) (ES: 1.7). The corresponding CIs were 25% - 77% and 0% - 26%, respectively. The mean factor of the overall explained variance was 1.29 with 1.04 - 1.61 CIs.

5. Discussion

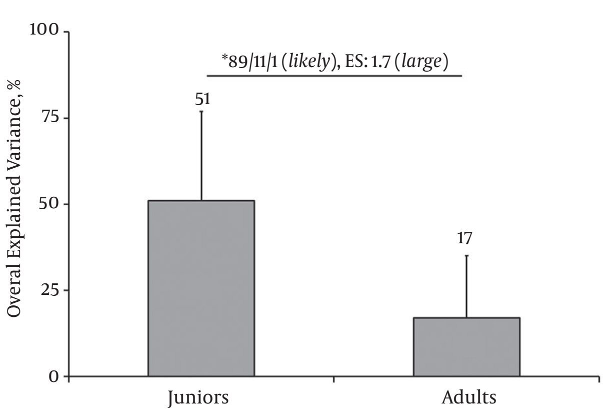
Our main findings in top-level handball players of different ages were: juniors (a) had lower anthropometric characteristics as well as maximum strength and intermittent endurance, but superior speed, COD, SJ, and core

Table 1. Differences in Anthropometric Characteristics and Physical Capacities Between Junior and Adult Top-Level Handball Players[a]

Variable	Juniors	Adults	Difference	SWD	Likelihood (%) for Juniors Having Higher/Similar/Lower Values (Descriptor)	ES (Descriptor)
	Mean (90% CI)	Mean (90% CI)	Mean (90% CI)			
Age, y	18 (18 - 19)	26 (24 - 29)	-8 (-10.6 - -5.5)	1	0/0/100 (most likely)	2.4 (very large)
Handball experience, y	10 (9 - 11)	19 (17 - 21)	-9 (-12 - -7)	1	0/0/100 (most likely)	2.5 (very large)
Height, m	1.84 (1.81 - 1.87)	1.90 (1.87 - 1.93)	-0.06 (-0.10 - -0.02)	0.01	0/2/98 (very likely)	0.9 (moderate)
Mass, kg	81.8 (76.3 - 87.3)	92.0 (88.5 - 95.5)	-10.2 (-16.5 - -3.9)	1.8	0/1/98 (very likely)	1.1 (moderate)
BMI, kg m^{-2}	24.0 (22.7 - 25.3)	25.6 (24.8 - 26.4)	-1.6 (-3.1 - -0.1)	0.4	2/7/91 (likely)	0.7 (moderate)
Fat, %	10.8 (9.1 - 12.5)	11.9 (10.6 - 13.2)	-1.1 (-3.1 - 0.9)	0.6	8/26/66 (unclear)	0.4 (small)
Fat-free mass, kg	72.8 (68.7 - 76.9)	81.0 (78.2 - 83.8)	-8.2 (-13.0 - -3.6)	1.4	0/1/99 (very likely)	1.2 (large)
Speed 5 m, s	1.08 (1.06 - 1.10)	1.12 (1.11 - 1.13)	-0.04 (-0.06 - -0.02)	0.01	0/1/99 (very likely)	1.3 (large)
Speed 10 m, s	1.81 (1.78 - 1.84)	1.87 (1.85 - 1.89)	-0.06 (-0.09 - -0.03)	0.01	0/1/99 (very likely)	1.1 (large)
Speed 20 m, s	3.08 (3.03 - 3.13)	3.16 (3.13 - 3.19)	-0.08 (-0.14 - -0.02)	0.02	0/4/96 (very likely)	0.9 (moderate)
Speed 30 m, s	4.27 (4.20 - 4.34)	4.34 (4.28 - 4.40)	-0.07 (-0.16 - 0.02)	0.03	3/19/78 (likely)	0.5 (small)
COD 22 m, s	5.54 (5.41 - 5.67)	5.75 (5.68 - 5.82)	-0.21 (-0.35 - -0.07)	0.04	0/2/97 (very likely)	1.0 (moderate)
SJ, cm	34.6 (32.9 - 36.3)	32.2 (30.7 - 33.7)	2.4 (0.2 - 4.6)	0.6	92/7/1 (likely)	0.8 (moderate)
CMJ, cm	42.2 (40.2 - 44.2)	40.4 (38.1 - 42.7)	1.8 (-1.1 - 4.7)	0.9	70/24/6 (unclear)	0.4 (small)
1RM Bench press, kg	91.0 (84.7 - 97.4)	101.8 (92.3 - 111.3)	-10.8 (-21.7 - 0.1)	3.0	2/9/89 (likely)	0.7 (moderate)
Core strength-endurance, s	574 (494 - 654)	381 (343 - 419)	193 (107 - 279)	24	99/0/0 (most likely)	1.6 (large)
ISRT, shuttles	98 (93 - 103)	107 (100 - 114)	-9.0 (-17 - -1)	2	2/6/92 (likely)	0.7 (moderate)

Abbreviations: CI, Confidence Interval; CMJ, Counter Movement Jump; COD, Change of Direction; ES, Effect size; ISRT, Interval Shuttle Run Test; SJ, Squat Jump; SWD, Smallest Worthwhile Difference; 1RM, One Repetition Maximum.
[a]The differences in the handball experience between both age groups are also shown.

Figure 2. Difference in Overall Explained Variances Among Speed, Change of Direction, and Jump Capacities Between Junior and Adult Top-Level Handball Players



Note: * = Likelihood (%) for juniors having a higher/similar/lower overall explained variance (descriptor); ES = Effect size (descriptor); scatter bars indicate 90% confidence intervals.

strength-endurance capacities; and (b) showed larger relationships among speed, COD, and jump capacities than adults.

For the first time, anthropometric characteristics and physical capacities were assessed by the same research design including various field tests in junior and adult handball players. For our adults, the mean measured body height (1.90 cm) and mass (92.0 kg) as well as 30 m speed (4.34 seconds), SJ (32.2 cm) and CMJ (40.4 cm), 1RM bench press (101.8 kg), and core strength-endurance (381 seconds) performance were supported by the values derived from previous studies (1.82 - 1.90 cm, 82.2 - 95.2 kg, 4.30 - 4.48 seconds, 31.0 - 36.6 cm, 34.2 - 46.8 cm, 99.3 - 106.9 kg, and 436 s, respectively) (8, 10, 11, 14, 17, 18, 22, 31-33). All further data of our adults were not comparable due to discrepancies in testing procedures (i.e., our COD and endurance tests were firstly conducted in handball) and methodologies (e.g., bioelectric impedance vs. skinfold calipers for body composition analyses (34), single vs. double timing gates and different procedures to trigger the start for sprint analyses (35), or impulse-momentum vs. flight-time

Table 2. Relationships Among Speed, Change of Direction, and Jump Capacities in Junior and Adult Top-Level Handball Players

Variable	Juniors r (90% CI) (Descriptor)	Adults r (90% CI) (Descriptor)	Ratio R^2 (90% CI)	SWR	Likelihood (%) for Juniors Having Higher/Similar/Lower R^2 (Descriptor)
Speed 5 m vs. Speed 30 m	0.86 (0.59 - 0.96) (very large)	0.61 (0.13 - 0.86) (large)	1.27 (1.03 - 1.57)	1.1	87/12/1 (likely)
Speed 5 m vs. COD 22 m	0.71 (0.26 - 0.91) (large)	0.45 (-0.14 - 0.80) (unclear)	1.25 (0.99 - 1.58)	1.1	83/16/2 (likely)
Speed 30 m vs. COD 22 m	0.64 (0.14 - 0.88) (large)	0.05 (-0.52 - 0.59) (unclear)	1.41 (1.17 - 1.69)	1.1	98/2/0 (very likely)
SJ vs. Speed 5 m	-0.84 (-0.95 - -0.54) (very large)	-0.05 (-0.56 - 0.49) (unclear)	1.70 (1.48 - 1.96)	1.1	100/0/0 (most likely)
SJ vs. Speed 30 m	-0.78 (-0.93 - -0.40) (very large)	-0.08 (-0.58 - 0.46) (unclear)	1.60 (1.36 - 1.87)	1.1	100/0/0 (most likely)
SJ vs. COD 22 m	-0.62 (-0.87 - -0.10) (large)	0.17 (-0.42 - 0.66) (unclear)	1.35 (1.11 - 1.63)	1.1	96/4/0 (very likely)
CMJ vs. Speed 5 m	-0.55 (-0.85 - 0.00) (large)	0.28 (-0.29 - 0.70) (unclear)	1.21 (0.99 - 1.48)	1.1	79/20/1 (likely)
CMJ vs. Speed 30 m	-0.59 (-0.86 - -0.06) (large)	0.07 (-0.47 - 0.57) (unclear)	1.34 (1.11 - 1.62)	1.1	96/4/0 (very likely)
CMJ vs. COD 22 m	-0.57 (-0.85 - -0.03) (large)	0.59 (0.06 - 0.86) (large)	0.98 (0.77 - 1.26)	1.1	22/48/30 (unclear)
CMJ vs. SJ	0.86 (0.59 - 0.96) (very large)	0.79 (0.45 - 0.93) (very large)	1.07 (0.89 - 1.30)	1.1	41/52/8 (unclear)

Abbreviations: CI, Confidence Interval; CMJ, Counter Movement Jump; COD, Change of Direction; r, Pearson Correlation Coefficient; R^2, Coefficient of Determination; SJ, Squat Jump; SWR, Smallest Worthwhile ratio.

method for jump analyses (36). For our juniors, no comparable data were available overall, because previous studies have investigated younger players (3, 16, 20, 24, 25). Taken together, compared to previous studies, our data provide additional and new knowledge into anthropometric characteristics and physical capacities of both junior and adult handball players, and thus, are worth being reported.

Regarding our first major finding, juniors had lower anthropometric characteristics as well as maximum strength and intermittent endurance capacities compared to adults (Table 1). Our detected differences were approximately 3-fold lower than those reported in one previous study for body height, mass, and fat-free mass as well as maximal handgrip strength, when comparing junior at 15 years and adult handball players (14). Plausibly, such differences between juniors and adults are caused by both naturally occurring growth, development, and maturation processes during puberty (e.g., via the hormonal mediated increases in fat-free mass, anaerobic capacities, or myelination of nerve fibers) (26) as well as additionally inducted long-term training adaptations (37), particularly according to resistance drills frequently performed in handball players (38) to physically prepare them for their playing demands (1). Overall, compared to adult handball players, the findings of our study and one previous study (14) show that differences in anthropometric characteristics and maximum strength capacities decrease in juniors from 15 to 18 years, but are still evident and of practical meaningfulness in 18 year old players (Table 1).

Further, our results demonstrate that juniors had a lower intermittent endurance capacity than adults (Table 1). Unfortunately, no study allowing comparison is available, because differences in this physical capacity between junior and adult handball players were firstly examined here. However, in other sports like soccer (39) and tennis (40), it has previously been shown that juniors aged 15 to 18 had a lower intermittent endurance capacity than adults. Likely, intermittent endurance associated differences between juniors and adults are related to differences in aerobic and anaerobic energy supplies (41), and may indicate here that there is a need to perform more repeated high-intensity running activities in adult handball level (7). Interestingly, our finding of differences in intermittent endurance and maximum strength capacities were less meaningful than those revealed in most anthropometric characteristics (Table 1). Therefore, it can be speculated that anthropometric characteristics, particularly body height and fat-free mass, are key physical determinants for playing handball in an top-level adults (10, 16).

A not expected outcome was that juniors had superior speed, COD, and SJ capacities compared to adults (Table 1). In handball, such differences have been reported for the first time. Nevertheless, in soccer (39) and futsal (42), it has already been shown that juniors aged 18 to 20 had superior speed and COD capacities to adults, which supports our unexpected findings. Since our identified differences decreased by longer sprinting distances and were also evident in the SJ capacity (Table 1), these outcomes may be affected by different capacities to accelerate, potentially for three main reasons: Firstly, it is known that the capacity to accelerate is impacted by the body mass (43), which is also supported by the findings of one previous study in adult handball players (23). Therefore, and because our juniors possessed less body mass (Table 1), a mass effect may explain their superior sprint and jump performances. Secondly, it is also known that the capacity to accelerate is influenced by the functioning of the neuromuscular system (e.g., neuronal drive, synchronization/recruitment/rate coding of motor units, or autogenic inhabitation) not only according to inherited talent or gained training adaptations (26), but also to experiencing musculoskeletal injuries (e.g., shown by lower electromyography median frequencies and amplitudes) (44). Consequently, and due to their shorter handball experiences (Table 1), our juniors may have experienced less musculoskeletal injuries, which may have favored the functioning of their neuromuscular system to perform fast and explosive movements. Lastly, compared to our adults, it is clear that the shorter handball experiences of our juniors are associated with less match play and training experiences. Thus, our juniors may be required to perform more “needless” sprints and jumps, which may also explain their superior performances from a long-term training adaptation perspective.

To finish the first major finding, juniors had a superior core strength-endurance capacity than adults (Table 1). To the best of our knowledge, no previous study has compared the core strength-endurance capacity between junior and adult athletes. However, during the last decade, core strength training has gained attention due to its postulated association with both performance enhancement and injury prevention (29). Therefore, the superior core strength-endurance capacity of our juniors may be caused by regularly performed core strength or further functional drills, and thus, reflects a long-term training adaptation according to their particular training content. Another possibility is again connected to their lower anthropometric characteristics (Table 1), because all applied core tests required the players to perform as many functional exercises as possible (Figure 1B-D) (29) for which particularly lower body masses and heights may have been beneficial.

Concerning our second main finding, juniors had larger relationships among speed, COD, and jump capacities than adults (Table 2). Regarding the relationships between jump and speed capacities, our findings were supported by those of one previous study each in junior (27) and adult (22) handball players, demonstrating comparable correlation coefficients (juniors: r = -0.65 - -0.68; adults: r = -0.45). Overall, the outcomes of our and previous studies (22, 27) show that speed and jump capacities were large to very large correlated in juniors, whereas both were unclear to moderate correlated in adults, indicating different associations between two important physical capacities for playing handball (1) in both age groups.

Additionally, compared to previous studies (22, 27), our study was the first to examine relationships not only between speed and jump capacities, but also concerning COD considered as a further essential physical capacity for playing handball (1, 15). In line with the found relationships between speed and jump capacities, in our juniors and adults, speed and COD capacities were large and unclear correlated, respectively (Table 2). Generally, it is accepted that speed and COD are independent physical capacities, because speed is predominantly determined by the neuromuscular system (e.g., neuronal drive, percentage of type II fibers, and anaerobic energy supply) (26), whereas COD also requires perceptual and decision making (e.g., visual scanning, pattern recognition, and anticipation) and change of direction aspects (e.g., technique and anthropometry) (45). However, in view of our examined sprinting distances, the 5 m speed capacity was more strongly correlated with the COD capacity than the 30 m speed capacity in both age groups (Table 2), showing a fundamental impact of the capacity to accelerate on COD (45). Lastly, we observed that jump and COD capacities were large and unclear to large correlated in our juniors and adults, respectively (Table 2), which is in line with our findings regarding jump and speed capacities. To conclude, these outcomes show that one further important physical capacity for playing handball, namely COD, was differently correlated with speed and jump capacities in junior and adult handball players.

To explain our observed different relationships among speed, COD, and jump capacities between juniors and adults overall, the most plausible explanation may be related to one different playing rule. In juniors, substitutions are only allowed during offensive playing phases, whereas they are permitted at any time in adults (46), potentially leading to different playing demands, and particularly, to a specialization regarding physical capacities in adults. This assumption is not only supported by our findings showing that overall more explained variance among speed, COD, and jump capacities could be explained in juniors than adults (Figure 2), but also by a previous study demonstrating that differences in physical capacities between playing positions were evident in adult, but not in 15 years old junior handball players (14).

From a practical point of view, our findings may help design different training and testing procedures for both age groups, and also assist in talent selection processes. For juniors, training drills should focus on speed, COD, jump, and core strength-endurance, whereas drills for adults should accentuate body composition, mainly body and fat-free mass, as well as maximum strength and intermittent endurance. Thereby, in juniors, one drill content (e.g., jumps) can impact several physical capacities (e.g., speed and COD), whereas this may not be the case in adults in whom separate drills to optimize each physical capacity are required. Furthermore, in juniors, one physical capacity test (e.g., for speed) may also allow conclusions regarding other fast and explosive capacities (e.g., COD and jump), whereas in adults separate tests are necessary. Lastly, our assessed data can be used as a framework to identify talented juniors and adults and particularly to modify the training content in talented juniors, when aiming to develop them toward prospective elite adults.

While our study provided new knowledge into anthropometric characteristics and physical capacities in top-level handball players, our findings were limited by the small sample sizes as indicated by some unclear outcomes (Table 1 and Table 2). Additionally, our findings could have been even more meaningful, if additional age groups or further important anthropometric characteristics, like segmental specific measures for body fat and fat-free mass (47), as well as physical capacities, such as ball throwing velocity (12), jumps involving opening steps (48), repeated-sprint ability (21), or performance circuits (1), would have also been tested. However, it must be reflected that our data were obtained from unique populations. This is especially true regarding our adults being World and European Champions. In such unique populations, it is difficult to increase the sample size and to conduct standardized testing procedures during the pre-season preparation without reducing the homogeneity and disturbing training-regeneration regimes, respectively.

In conclusion, this study shows that differences in anthropometric characteristics and physical capacities, and also in relationships among physical capacities, are evident between junior and adult top-level handball players, indicating different physical needs to play handball.

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Footnotes

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References

1. Wagner H, Finkenzeller T, Wurth S, von Duvillard SP. Individual and team performance in team-handball: a review. *J Sports Sci Med.* 2014;**13**(4):808–16. [PubMed: 25435773].

2. Barbero JC, Granda-Vera J, Calleja-González J, Del Coso J. Physical and physiological demands of elite team handball players. *Int J Perform Anal Sport.* 2014;**14**(3):921–33.
3. Povoas SC, Seabra AF, Ascensao AA, Magalhaes J, Soares JM, Rebelo AN. Physical and physiological demands of elite team handball. *J Strength Cond Res.* 2012;**26**(12):3365–75. doi: 10.1519/JSC.0b013e318248aeee. [PubMed: 22222325].
4. Ziv G, Lidor R. Physical charactristics, physiological attributes, and on-court performances of handball players: A review. *Eur J Sport Sci.* 2009;**9**(6):375–86.
5. Luig P, Manchado C, Pers J. Motion characteristics according to playing positions in international men's team handball. 13th Annual ECSS-Congress. Estoril, Portugal. .
6. Michalsik LB, Aagaard P, Madsen K. Physical demands in elite team handball: comparisons between male and female players. 17th Annual ECSS-Congress. Bruges, Belgium. .
7. Chelly MS, Hermassi S, Aouadi R, Khalifa R, Van den Tillaar R, Chamari K, et al. Match analysis of elite adolescent team handball players. *J Strength Cond Res.* 2011;**25**(9):2410–7. doi: 10.1519/JSC.0b013e3182030e43. [PubMed: 21869627].
8. Michalsik LB, Madsen K, Aagaard P. Physiological capacity and physical testing in male elite team handball. *J Sports Med Phys Fitness.* 2015;**55**(5):415–29. [PubMed: 24402441].
9. Karcher C, Buchheit M. On-court demands of elite handball, with special reference to playing positions. *Sports Med.* 2014;**44**(6):797–814. doi: 10.1007/s40279-014-0164-z. [PubMed: 24682948].
10. Ghobadi H, Rajabi H, Farzad B, Bayati M, Jeffreys I. Anthropometry of World-Class Elite Handball Players According to the Playing Position: Reports From Men's Handball World Championship 2013. *J Hum Kinet.* 2013;**39**:213–20. doi: 10.2478/hukin-2013-0084. [PubMed: 24511357].
11. Sporis G, Vuleta D, Vuleta DJ, Milanovic D. Fitness profiling in handball: physical and physiological characteristics of elite players. *Coll Antropol.* 2010;**34**(3):1009–14. [PubMed: 20977096].
12. Kruger K, Pilat C, Uckert K, Frech T, Mooren FC. Physical performance profile of handball players is related to playing position and playing class. *J Strength Cond Res.* 2014;**28**(1):117–25. doi: 10.1519/JSC.0b013e318291b713. [PubMed: 23539084].
13. Ingebrigtsen J, Jeffreys I, Rodahl S. Physical characteristics and abilities of junior elite male and female handball players. *J Strength Cond Res.* 2013;**27**(2):302–9. doi: 10.1519/JSC.0b013e318254899f. [PubMed: 22465989].
14. Nikolaidis PT, Ingebrigtsen J, Povoas SC, Moss S, Torres-Luque G. Physical and physiological characteristics in male team handball players by playing position - Does age matter? *J Sports Med Phys Fitness.* 2015;**55**(4):297–304. [PubMed: 25303066].
15. Iacono AD, Eliakim A, Meckel Y. Improving fitness of elite handball players: small-sided games vs. high-intensity intermittent training. *J Strength Cond Res.* 2015;**29**(3):835–43. doi: 10.1519/JSC.0000000000000686. [PubMed: 25226326].
16. Mohamed H, Vaeyens R, Matthys S, Multael M, Lefevre J, Lenoir M, et al. Anthropometric and performance measures for the development of a talent detection and identification model in youth handball. *J Sports Sci.* 2009;**27**(3):257–66. doi: 10.1080/02640410802482417. [PubMed: 19153859].
17. Massuca LM, Fragoso I, Teles J. Attributes of top elite team-handball players. *J Strength Cond Res.* 2014;**28**(1):178–86. doi: 10.1519/JSC.0b013e318295d50e. [PubMed: 23591948].
18. Gorostiaga EM, Granados C, Ibanez J, Izquierdo M. Differences in physical fitness and throwing velocity among elite and amateur male handball players. *Int J Sports Med.* 2005;**26**(3):225–32. doi: 10.1055/s-2004-820974. [PubMed: 15776339].
19. Nikolaos O, Dimitrios H, Charalambos I, Theodoros I, Savvas L, Aggelos K, et al. Evaluation of high-level handball players in morphological characteristics and various motor abilities by playing position. *Eur J Sport Sci.* 2014;**1**(2):21–8.
20. Matthys SP, Vaeyens R, Fransen J, Deprez D, Pion J, Vandendriessche J, et al. A longitudinal study of multidimensional performance characteristics related to physical capacities in youth handball. *J Sports Sci.* 2013;**31**(3):325–34. doi: 10.1080/02640414.2012.733819. [PubMed: 23078540].
21. Schwesig R, Hermassi S, Fieseler G, Irlenbusch L, Noack F, Delank KS, et al. Anthropometric and physical performance characteristics of professional handball players: Influence of playing position and competitive level. *J Sports Med Phys Fitness.* 2016.
22. Chaouachi A, Brughelli M, Levin G, Boudhina NB, Cronin J, Chamari K. Anthropometric, physiological and performance characteristics of elite team-handball players. *J Sports Sci.* 2009;**27**(2):151–7. doi: 10.1080/02640410802448731. [PubMed: 19051095].
23. Moncef C, Said M, Olfa N, Dagbaji G. Influence of morphological characteristics on physical and physiological performances of tunisian elite male handball players. *Asian J Sports Med.* 2012;**3**(2):74–80. [PubMed: 22942992].
24. Zapartidis I VIGMKP. Physical fitness and anthropometric characteristics in different levels of young team handball players. *Open Sport Sci J.* 20090;**2**:22–8.
25. Visnapuu M, Jurimae T. Relations of anthropometric parameters with scores on basic and specific motor tasks in young handball players. *Percept Mot Skills.* 2009;**108**(3):670–6. doi: 10.2466/PMS.108.3.670-676. [PubMed: 19725303].
26. Kenney WL, Wilmore JH, Costill DL. Physiology of sport and exercise. *Human Kinetics J.* 2015.
27. Ingebrigtsen J, Jeffreys I. The relationship between speed, strength and jumping abilities in elite junior handball players. *Serb J Sports Sci.* 2012;**6**(3):83–8.
28. Hoppe MW, Baumgart C, Sperlich B, Ibrahim H, Jansen C, Willis SJ, et al. Comparison between three different endurance tests in professional soccer players. *J Strength Cond Res.* 2013;**27**(1):31–7. doi: 10.1519/JSC.0b013e31824e1711. [PubMed: 22344049].
29. Hoppe MW, Freiwald J, Baumgart C, Born DP, Reed JL, Sperlich B. Relationship between core strength and key variables of performance in elite rink hockey players. *J Sports Med Phys Fitness.* 2015;**55**(3):150–7. [PubMed: 25069961].
30. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc.* 2009;**41**(1):3–13. doi: 10.1249/MSS.0b013e31818cb278. [PubMed: 19092709].
31. Massuca L, Branco B, Miarka B, Fragoso I. Physical Fitness Attributes of Team-Handball Players are Related to Playing Position and Performance Level. *Asian J Sports Med.* 2015;**6**(1):e24712. doi: 10.5812/asjsm.24712. [PubMed: 25883775].
32. Nikolaidis PT, Ingebrigtsen J. Physical and physiological characteristics of elite male handball players from teams with a different ranking. *J Hum Kinet.* 2013;**38**:115–24. doi: 10.2478/hukin-2013-0051. [PubMed: 24235989].
33. Tschopp M. Leistungsdiagnostik kraft. *Swiss Olympic Med Cent.* 2003.
34. Williams CA, Bale P. Bias and limits of agreement between hydrodensitometry, bioelectrical impedance and skinfold calipers measures of percentage body fat. *Eur J Appl Physiol Occup Physiol.* 1998;**77**(3):271–7. doi: 10.1007/s004210050332. [PubMed: 9535589].
35. Haugen T, Buchheit M. Sprint Running Performance Monitoring: Methodological and Practical Considerations. *Sports Med.* 2016;**46**(5):641–56. doi: 10.1007/s40279-015-0446-0. [PubMed: 26660758].
36. Linthorne NP. Analysis of standing vertical jumps using a force platform. *Am J Phys.* 2001;**69**(11):1198.
37. Bompa T, Haff G. Periodization - theory and methodology of training. *Human Kinetics J.* 2009.
38. Chelly MS, Hermassi S, Aouadi R, Shephard RJ. Effects of 8-week in-season plyometric training on upper and lower limb performance of elite adolescent handball players. *J Strength Cond Res.* 2014;**28**(5):1401–10. doi: 10.1519/JSC.0000000000000279. [PubMed: 24149768].

39. Mujika I, Santisteban J, Impellizzeri FM, Castagna C. Fitness determinants of success in men's and women's football. *J Sports Sci.* 2009;**27**(2):107–14. doi: 10.1080/02640410802428071. [PubMed: 19058090].
40. Ferrauti A, Kinner V, Fernandez-Fernandez J. The Hit & Turn Tennis Test: an acoustically controlled endurance test for tennis players. *J Sports Sci.* 2011;**29**(5):485–94. doi: 10.1080/02640414.2010.539247. [PubMed: 21294033].
41. Lemmink KA, Visscher SH. Role of energy systems in two intermittent field tests in women field hockey players. *J Strength Cond Res.* 2006;**20**(3):682–8.
42. Nakamura FY, A Pereira L, Cal Abad CC, Kobal R, Kitamura K, Roschel H, et al. Differences in physical performance between u-20 and senior top-level Brazilian futsal players. *J Sports Med Phys Fitness.* 2015.
43. Haugen T, Tonnessen E, Seiler S. 9.58 and 10.49: nearing the citius end for 100 m? *Int J Sports Physiol Perform.* 2015;**10**(2):269–72. doi: 10.1123/ijspp.2014-0350. [PubMed: 25229725].
44. Drechsler WI, Cramp MC, Scott OM. Changes in muscle strength and EMG median frequency after anterior cruciate ligament reconstruction. *Eur J Appl Physiol.* 2006;**98**(6):613–23. doi: 10.1007/s00421-006-0311-9. [PubMed: 17036217].
45. Sheppard JM, Young WB. Agility literature review: classifications, training and testing. *J Sports Sci.* 2006;**24**(9):919–32. doi: 10.1080/02640410500457109. [PubMed: 16882626].
46. Deutscher Handball Bund . Internationale Handball-Regeln mit den DHB Zusatzbestimmungen. *Handball Marketinggesellschaft mbH (HMG).* 2013.
47. Yamada Y, Masuo Y, Nakamura E, Oda S. Inter-sport variability of muscle volume distribution identified by segmental bioelectrical impedance analysis in four ball sports. *Open Access J Sports Med.* 2013;**4**:97–108. doi: 10.2147/OAJSM.S43512. [PubMed: 24379714].
48. Hubner K, Knoll K, Bronst A, Marti B. Sprungwurf korreliert nicht mit Testwerten der Kraftmessplatte. *Schweiz Z Med Traumatol.* 2005;**53**(3):101–4.