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Jumping ability is related to change of direction ability in elite handball players

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ABSTRACT

Purpose: This study investigated the relationship between vertical and horizontal jumping ability and change of direction (COD) to measure athletic performance in 51 elite male handball players.
Scope.
Countermovement jump (CMJ), peak power, and standing long jump (SLJ) were measured. Participants performed a 20-m sprint test (time measured at 5, 10, and 20 m) and a zigzag test (COD: 135°, 90°, and 45°). The COD deficit, an index of the time required for COD, was calculated. The correlations between CMJ height and zigzag test times were relatively large (at 135°, $r = -0.607$; at 90°, $r = -0.594$; at 45°, $r = -0.613$; $p < 0.01$), whereas those between CMJ height and COD deficit were moderate (at 135°, $r = -0.399$, $p < 0.01$; at 90°, $r = -0.350$, $p < 0.05$; at 45°, $r = -0.323$, $p < 0.05$). SLJ showed a negative moderate correlation with COD deficit (at 135°, $r = -0.439$, $p < 0.01$; at 90°, $r = -0.469$, $p < 0.01$; at 45°, $r = -0.380$, $p < 0.01$).
Conclusions: This study is the first to analyse SLJ ability and COD deficit parameters of handball players. We found that SLJ ability is moderately related to COD time and deficit; therefore, SLJ measurement may be a useful predictor of athletic performance.

1. Introduction

The physiological evaluation of athletes provides an effective and reliable means of measuring properties important for sports performance (Gore et al, 2012). Studies have used the countermovement jump (CMJ) as a field test in athletes to investigate the explosive power of their lower extremities (Abade et al, 2019; Freitas et al, 2019). In handball, jump height and jump distance may determine players' in-match jumping ability. Notably, CMJ is frequently used to measure lower limb strength in soccer and handball players (Loturco et al, 2018; Pereira et al, 2018) and has been reported to be associated with 800-m time in track and field athletes ($r = -0.69$, $p < 0.01$) (Bachero et al, 2017). In addition, standing long jump (SLJ) has been reported to be related to athletic performance scores (World Athletics Scoring Table) in track and field athletes ($r = 0.29$, $p < 0.05$) (Aoki et al, 2015). Moreover, the horizontal jumping ability has also been used to measure athletic ability. Studies have shown that horizontal jumping has a relationship with sprinting velocity and vertical jump (correlation coefficients: vertical jump, $r = 0.908$; SLJ, $r = 0.856$) (Peterson et al, 2006). Although horizontal jumping measurements are more convenient because no special equipment is required, they are not commonly used in research studies. Therefore, the relationship between the change of direction (COD), especially in zigzag or sprint test, and horizontal jumping is not yet determined.

In team sports, the speed of both straight and directional movements, such as running with a COD, is a clear determinant of performance (Gore et al, 2012). The COD test has traditionally been used to measure COD ability, and a more recently used method is the 20-m zigzag test (Loturco et al, 2018). Studies have performed COD ability measurements at a single angle of the zigzag test (COD angle: 100°) (Pereira et al., 2018). Multiple factors determine COD capability (Sheppard et al., 2006), including sprinting ability, lower limb strength, and jumping ability (Pereira et al, 2018; Young et al, 2002). However, the relationship between the zigzag test from several angles and the SLJ has not been determined.

The COD test is strongly related to linear sprinting ability; therefore, the value generated by subtracting the linear sprinting time for the same distance from the COD test can be considered the COD deficit. However, a previous study showed that COD deficit was correlated with the COD test time ($r = 0.74$–0.81) but not with the sprint time ($r = -0.11$–0.097)

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(Nimphius et al, 2016). Therefore, COD deficit is considered an independent factor associated with the linear sprinting ability (Nimphius et al, 2016). The COD deficit is calculated using the time of the COD run and the time of the linear run of the same distance (e.g., 20-m zigzag test time − 20-m linear sprint time). Therefore, the 'time required to change direction' can be calculated without expensive equipment. As COD deficit is indirectly related to a 'change of direction technique', its correlation with physical fitness has been investigated. Since handball frequently entails jumping, it is better to measure jumping to evaluate the ability of each player. In particular, SLJ can be easily measured because it only needs a tape measure. However, there is currently no research on the relationship between COD deficit and SLJ.

Changes in handball rules have increased the physical demands of players (Michalsik et al, 2018). Moreover, the movements of the players have become quicker because the referees are now expected to operate a fast-developing game with as few interruptions as possible (IHF, 2021; Japan Handball Association, 2019); thus, the linear sprint and COD become more important. However, the recent coronavirus disease (COVID-19) pandemic has limited the amount of team training. Therefore, determining skills beneficial to handball players that can be measured individually without requiring special equipment is essential. Moreover, sprinting ability depends not only on lower limb strength but also on kinematics, such as step frequency and step stride length. A previous study found that step rate was related to flight time ($r = -0.81$, $p < 0.01$), and step length was related to flight distance ($r = 0.89$, $p < 0.01$) (Hunter et al, 2004). However, utilising the correlation between sprint time and COD time may be inappropriate for training high school handball players because the growth rate varies from person to person, potentially affecting sprint technique due to different body statures or body masses. Notably, focusing on lower limb strength can help athletes to improve their performance.

The purpose of this study was to investigate the relationship between jumping ability (vertical and horizontal) and COD tests in elite handball players. We hypothesised that players could improve their skills by improving their horizontal jumping ability, which is a skill that can be trained in small spaces.

2. Methods

2.1. Study design

Measurements were performed during the pre-season training on an indoor field with a wooden floor between 16:00 and 19:00. The building's temperature was between 15 °C and 21 °C, and the humidity was between 28% and 59%. Participants were instructed not to eat 2 h before measurements or drink beverages containing caffeine from the morning of the testing day. Stature and body mass were measured, and participants performed a warm-up routine that included stretching and running at low speeds.

2.2. Participants

Participants aged 15–17 years were recruited from four senior championship high school teams in November 2019, and they attended five handball practice sessions and one strength-training session per week. The four teams whose measurements were completed before the spread of COVID-19 were included in the analysis. Sixty-two male handball players agreed to participate in the study; however, 11 goalkeepers were excluded from the study population because their positional movement patterns differed from those in field positions. The final analysis included 51 participants. The sample size was calculated using G*Power version 3.1 (Faul et al, 2007, 2009). The variances of the measurements were equal, and a normal distribution was guaranteed. The results of the G*Power with a sensitivity test indicated that using this sample size enabled detection of a correlation of 0.47 as statistically significant with 95% power and $p < 0.05$. Therefore, our sample size is meaningful. Data were analysed in August 2020.

All the participants in this study were younger than 18 years. Therefore, we first explained the study design to their parents or guardians. After obtaining written informed consent from the parents or guardians to participate, we asked the participants to assent when they were gathered on the measurement day. The participants were informed of the study's purpose, method, and risks in writing ahead of participation. On the day of measurement, we gave explanatory documents and verbal explanations, including explanations of the actual measurement methods. Athletes who assented to participate in the measurement were included in this analysis. The study protocol was approved by the Ethics Committee of the School of Health and Sports Science at Juntendo University (approval no. 31–1) and followed the principles of the Declaration of Helsinki (WMA, 2008).

2.3. Anthropometry

The stature of participants was measured to an accuracy of 0.1 cm using a stadiometer (YL-65; Yagami, Nagoya, Japan). Body weight was measured to an accuracy of 0.01 kg using a digital weighing scale (Precision Personal Health Scale A4-sized Weight Watcher, UC-322; A&D Company Limited, Tokyo, Japan). Using these measurements, the body mass index (BMI) was calculated.

2.4. Twenty-meter sprint test

The 20-m sprint test was performed twice. Times were measured to the nearest 0.01 s. The fastest time for each participant was used in the final analysis. The flying start format was used to initiate the time to eliminate the influence of reaction time. The starting position was 30 cm behind the electronic timing gate, and a standing start posture was used. A minimum of 3 min of rest was allowed between measurements. Participants performed a 20-m sprint test as previously described by Pereira et al (2018). Time was measured using a single-beam electronic timing gate (TC; Brower Timing System, Draper, UT, USA). The electronic timing gate was installed at a height of 1.0 m. The times required to reach the 5- and 10-m points were also recorded simultaneously to evaluate acceleration.

2.5. Countermovement jump

We measured vertical jumping ability using CMJ as previously described by Pereira et al (2018). Participants were asked to jump as high as possible by dropping their hips from a standing position to a half squat and then rebounding from that position. Sinking depth was free within the range in which movement (jump height) did not change. This measurement was performed with both hands on the hips to prevent rebound due to arm swings. All jumps were performed on a switch mat (Multi-jump-tester, IFS-31D; DKH, Tokyo, Japan) to measure the air and contact time as previously described (Nagahara et al, 2014). Using the measured flight time (t) and gravity-induced acceleration (g), the jump height was estimated as previously described by Asmussen and Bonde-Peterson (1974) using the following formula:

$$Jump\ height = t^2 \times g/8 \quad (1)$$

2.6. Standing long jump

We evaluated the horizontal jumping ability using SLJ as previously described by Peterson et al (2006). Participants were asked to stand on both legs and leap forward as far as possible and land on both legs in a wooden floor. The distance between the toe position at the start of the jump and the heel position during landing was measured with a steel measuring tape (Promart, 5.5 m Econ 19; Hara Rule Mfg. Co. Ltd, Kanagawa, Japan). SLJ was performed twice, and the higher of the two measurements was used for the final analysis.

2.7. Power estimation

Peak power was estimated from CMJ height as previously described by Sayers et al (1999) using the following formula:

$$peak\ power\ (w) = 60.7 \times jump\ height\ (cm) + 45.3 \times body\ mass\ (kg) - 2,055 \quad (2)$$

2.8. Zigzag test

A zigzag running test was used to measure COD ability. The time was measured using the electronic timing gate used for the sprint test. The running course was Z-shaped with three cones placed at 5-m intervals over a total distance of 20 m. As previously described (Lockie et al, 2013), COD angles of 45° (135°) and − 45° (45°) were evaluated, with 90° as a reference (Fig. 1). COD deficit indices were calculated using sprint and zigzag test results with the following previously reported formula (Nimphius et al, 2016):

$$COD\ deficit\ (s) = zigzag\ test\ time\ (s) - 20 - m\ sprint\ time\ (s) \quad (3)$$

2.9. Statistical analyses

All results are shown as means ± standard deviations. The intraclass correlation coefficient (ICC) was used to evaluate the reliability of the measurement results. ICC interpretation was performed as previously described by Koo and Li (2016) as follows: poor, <0.5; moderate, 0.5–0.75; good, 0.75–0.90; excellent, >0.90. The Pearson coefficient was used to determine the relationship between COD and linear sprint time. The partial correlation coefficient was calculated using several control variables, including BMI and sprint time at 5, 10, and 20 m. The interpretation of the correlation coefficients was based on the criteria proposed by Hopkins et al (2009) (<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; >0.9: nearly perfect). All statistical analyses were performed using IBM SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY, USA), and statistical significance was set at $p < 0.05$.

3. Results

Table 1 shows the results of the sprint, jump, and COD tests and participants' demographics. The ICCs of measurement items ranged from 0.81 to 0.95. Table 2 shows the relationships between jumping ability and other parameters. The relationships between CMJ height and other measurements varied from very large to moderate as follows: very large, CMJ height and 20-m sprint time ($r = -0.72$, $p < 0.01$) or peak power ($r = 0.71$, $p < 0.01$); large, CMJ height and 10-m sprint time ($r = -0.66$, $p < 0.01$); and moderate, CMJ height and 5-m sprint time ($r = -$

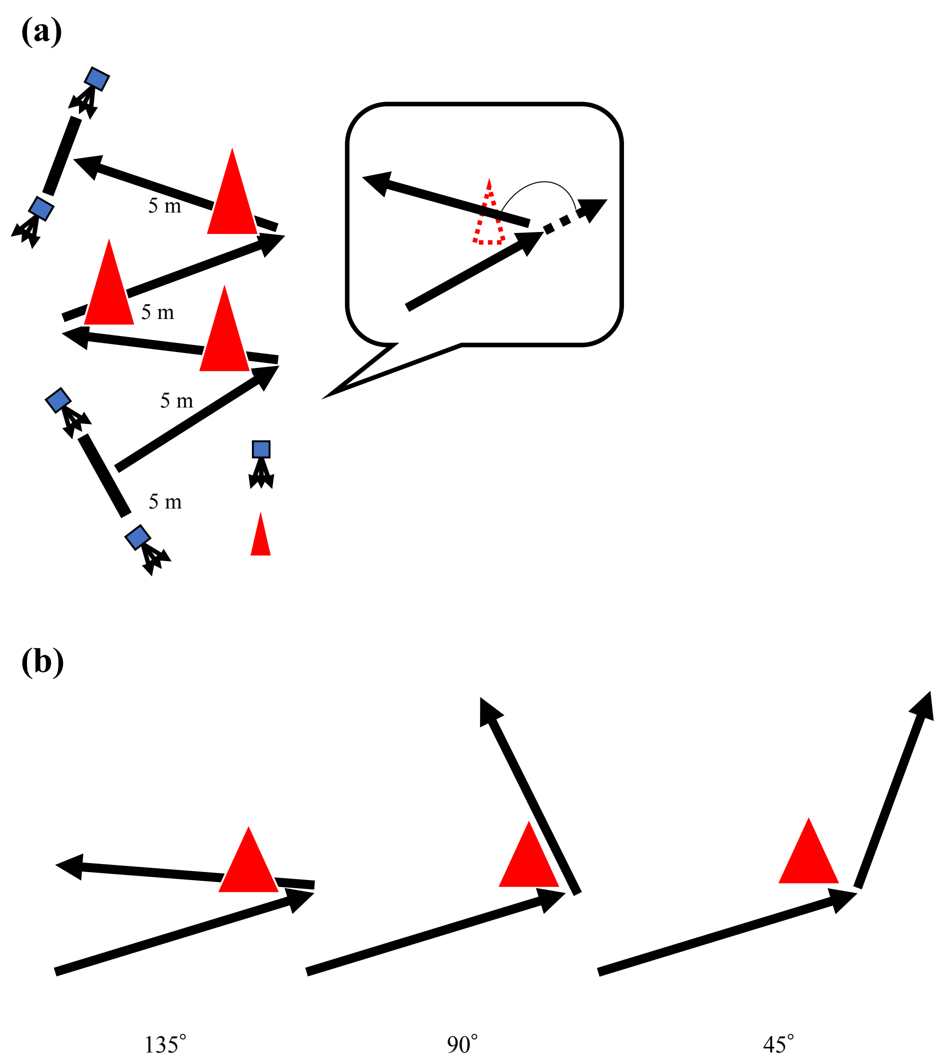

Fig. 1. (a) Schematic diagram of the zigzag running test course used in this study. (b) Different angles of the changes of the direction manoeuvre used in the zigzag test. For example, first COD: 135°; second COD: 135°; third COD: 135°.

Table 1
Participant demographics and sprinting, jumping, and COD test results.

		Mean ± SD	CV	ICC
Demographics				
	Age (years)	16.2 ± 0.7	0.04	
	Experience (years)	6.2 ± 2.3	0.37	
	Height (cm)	170.1 ± 4.7	0.03	
	Weight (kg)	65.92 ± 8.08	0.12	
	BMI (kg/m^2)	22.7 ± 2.3	0.10	
Sprinting ability				
Time (s)	5 *m*	1.09 ± 0.07	0.06	0.83
	10 *m*	1.83 ± 0.10	0.05	0.89
	20 *m*	3.15 ± 0.16	0.05	0.91
Jumping ability				
	CMJ (cm)	42.5 ± 6.4	0.15	0.95
	Peak power (w)	3,510.65 ± 515.16	0.15	
	SLJ (cm)	236 ± 18	0.08	0.84
COD ability				
COD(s)	135°	5.88 ± 0.34	0.06	0.81
	90°	4.95 ± 0.32	0.06	0.88
	45°	3.86 ± 0.27	0.07	0.88
COD deficit	135°	2.73 ± 0.24	0.09	
	90°	1.80 ± 0.22	0.12	
	45°	0.71 ± 0.17	0.24	

BMI, body mass index; CI, confidence interval; CMJ, countermovement jump; COD, change of direction; CV, coefficient of variation; ICC, intraclass correlation coefficient; SLJ, standing long jump; SD, standard deviation.

Table 2
Correlations between sprinting and jumping abilities.

	5-m sprint	10-m sprint	20-m sprint	CMJ	Peak power
10-m sprint	0.92**				
20-m sprint	0.84**	0.95**			
CMJ	−0.44**	−0.66**	−0.72**		
Peak power	−0.02	−0.22	−0.25	0.71**	
SLJ	−0.44**	−0.65**	−0.73**	0.81**	0.48**

*$p < 0.05$, **$p < 0.01$.
CMJ, countermovement jump; SLJ, standing long jump.

0.44, $p < 0.01$). In addition, the relationships were very large between SLJ and 20-m sprint time ($r = -0.73$, $p < 0.01$) or CMJ height ($r = 0.81$, $p < 0.01$), large between SLJ and 10-m sprint time ($r = -0.65$, $p < 0.01$), and moderate between SLJ and 5-m sprint time ($r = -0.44$, $p < 0.01$) or peak power ($r = 0.48$, $p < 0.01$) (Fig. 2).

Table 3 and Fig. 3a, b, 4a, and b show the relationships between the zigzag test time, deficit, and other parameters. The relationships between zigzag test times at 135°, 90°, and 45° and other measurements were as follows: very large: zigzag test times and 20- or 10-m sprint times (at 135°: $r = 0.790$ and 0.734, respectively; at 90°: $r = 0.769$ and 0.721, respectively; at 45°: $r = 0.806$ and 0.768, respectively; $p < 0.01$) and large: zigzag test times and 5-m sprint time, CMJ height, or SLJ (at 135°: $r = 0.594$, −0.607, and − 0.642, respectively; at 90°: $r = 0.561$, −0.594, and − 0.684, respectively; at 45°: $r = 0.655$, −0.613, and − 0.658, respectively; $p < 0.01$). The relationship between zigzag test 135° deficit and the other measurements were moderate with 20-, 10-, and 5-m sprint time; CMJ height; and SLJ ($r = 0.476$, 0.431, 0.300, −0.399, and − 0.439, respectively; $p < 0.01$, 0.01, 0.05, 0.01, and 0.01, respectively). The relationship between zigzag test 90° deficit and the other measurements were moderate with 20- and 10-m sprint time, CMJ height, and SLJ ($r = 0.404$, 0.373, −0.350, and − 0.469, respectively; $p < 0.01$, 0.01, 0.05 and 0.01, respectively). The relationship between zigzag test 45° deficit and the other measurements were moderate with 20- and 10-m sprint time, CMJ height, and SLJ ($r = 0.376$, , 0.363, − 0.323, − 0.380, respectively; $p < 0.01$, 0.01, 0.05, and 0.01, respectively).Fig. 5.Fig. 6.

Table 4 shows the correlations of COD with other parameters when BMI was controlled. The relationships between zigzag test at 135° and other measurements were very large with 20-m sprint time ($r = 0.722$, $p < 0.01$) and large with 10-m sprint time, CMJ height, peak power, and SLJ ($r = 0.657$, −0.675, −0.606, and − 0.611, respectively; $p < 0.01$). The relationship between zigzag test at 90° and other measurements were large ($r = 0694$, $p < 0.01$) with 20-m sprint time, and large with 10-m sprint time, CMJ height, peak power, and SLJ ($r = 0.639$, −0.659, −0.640, and − 0.662, respectively; $p < 0.01$). The relationship between zigzag test at 45° and other measurements were very large with 20-m sprint time ($r = 0.742$, $p < 0.01$) and large with 10- and 5-m sprint time, CMJ height, peak power, and SLJ ($r = 0.699$, 0.539, −0.689, −0.649, and − 0.632, respectively; $p < 0.01$). Furthermore, the relationship between 135° COD deficit, and all jumping ability was moderate with CMJ height, peak power, and SLJ ($r = -0.415$, −0.343, and − 0.374, respectively; $p < 0.01$, 0.05, and 0.01, respectively), moderate with 20-m sprint time ($r = 0.345$, $p < 0.05$), and small with 10-m sprint time ($r = 0.298$, $p < 0.05$). The 90° COD deficit and all jumping ability were moderate with CMJ height, peak power, and SLJ ($r = -0.358$, −0.356, and − 0.411, respectively; $p < 0.05$, 0.05, and 0.01, respectively) and 45° COD deficit and all jumping ability were moderate with CMJ height, peak power, and SLJ ($r = -0.329$, −0.302, −0.309, respectively; $p < 0.05$). Table 5 shows the correlation between COD and other parameters when sprint time is controlled. A positive small correlation was found between the zigzag test at 135° and peak power ($r = 0.282$, $p = 0.053$). A positive small correlation was found between the COD deficit at 135° and peak power ($r = 0.282$, $p = 0.053$).

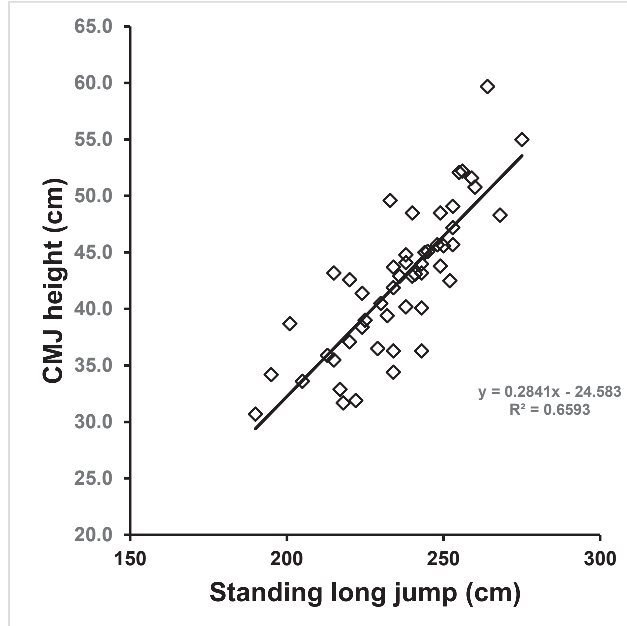

Fig. 2. Relationship between countermovement jump (CMJ) height and standing long jump ($n = 51$, $r^2 = 0.6593$, $p < 0.01$).

4. Discussion

To the best of our knowledge, this study is the first to examine the COD deficit and jumping ability of various angles in the zigzag test and evaluate various angles of COD deficit and jumping ability in elite Japanese senior high school handball players. We found that CMJ and SLJ were largely related to COD time (CMJ 135°, 90°, and 45°: $r = -0.607$, −0.594, and − 0.613, respectively; SLJ 135°, 90°, and 45°: $r = -0.642$, −0.684, and − 0.658, respectively). The correlation between COD deficit and jumping ability (CMJ and SLJ) was moderate (CMJ 135°, 90°, and 45°: $r = -0.399$, −0.350, and − 0.323, respectively; SLJ 135°, 90°, and 45°: $r = -0.439$, −0.469, and − 0.380, respectively). We also found that linear sprinting ability was related to COD time based on the zigzag test results and COD deficits.

Table 3
Correlations among demographics, sprinting ability, jumping ability, and the change of direction.

	Anthropometry		Sprint ability			Jump ability		
	Body height	Body mass	5-m time	10-m time	20-m time	CMJ height	Peak power	SLJ
135° time	0.125	0.485**	0.594**	0.734**	0.790**	−0.607**	−0.113	−0.642**
90° time	0.023	0.434**	0.561**	0.721**	0.769**	−0.594**	−0.139	−0.684**
45° time	0.068	0.468**	0.655**	0.768**	0.806**	−0.613**	−0.130	−0.658**
135° deficit	0.156	0.423**	0.300*	0.431**	0.476**	−0.399**	0.000	−0.439**
90° deficit	0.007	0.332*	0.217	0.373**	0.404**	−0.350*	−0.028	−0.469**
45° deficit	0.074	0.366**	0.279*	0.363**	0.376**	−0.323*	0.016	−0.380**

*$p < 0.05$, **$p < 0.01$.
CMJ, countermovement jump; SLJ, standing long jump.

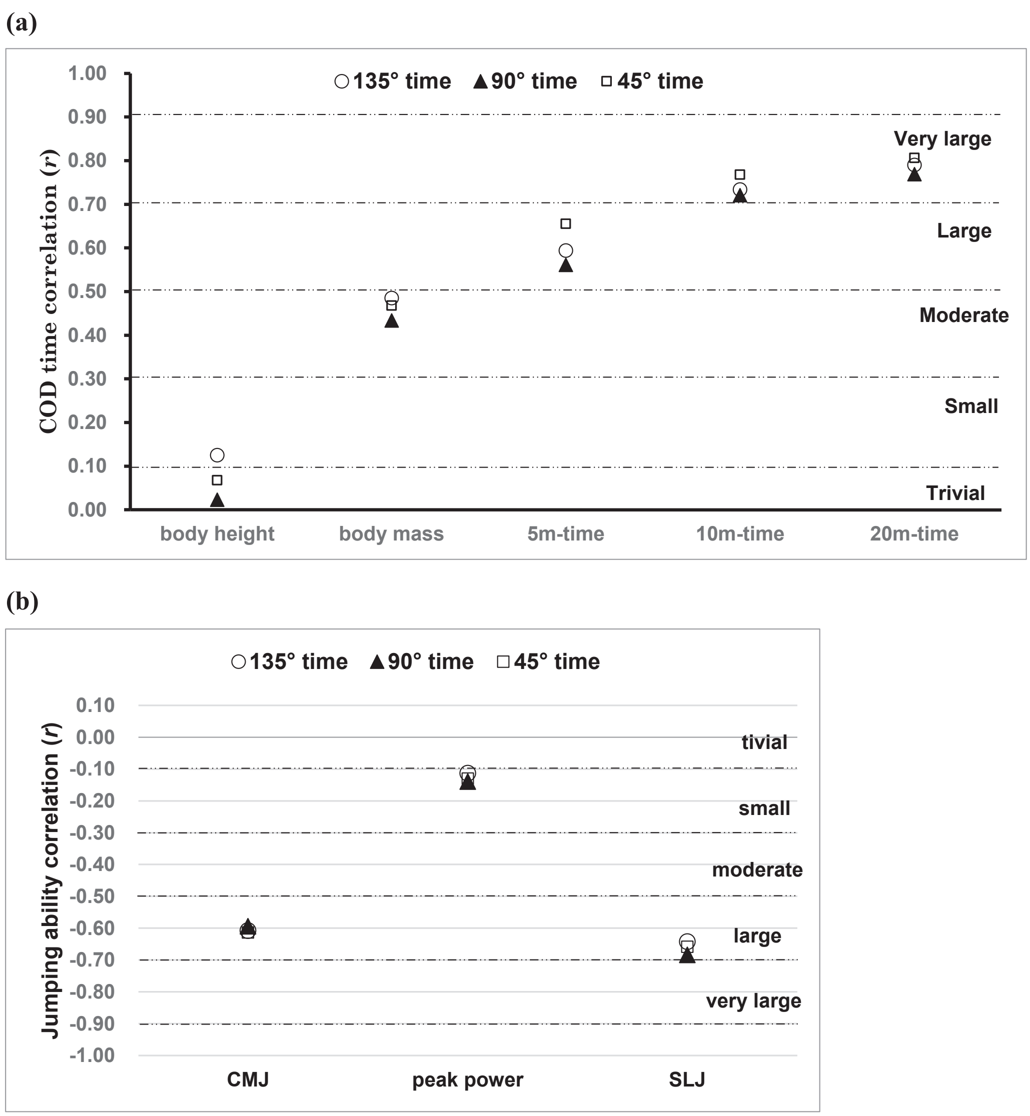

Fig. 3. (a) Relationship between zigzag test time and other measurements. (b) Relationship between zigzag test time and jumping ability. COD, change of direction; CMJ, countermovement jump; SLJ, standing long jump.

A previous study reported a correlation between CMJ and SLJ ($r = 0.835$, $p < 0.01$) (Peterson et al, 2006), and in the current study, the strength of this correlation was very large ($r = 0.81$, $p < 0.01$; Fig. 2). Another study found that the five-jump test was related to squat jump height ($r = 0.72$, $p = 0.002$) and arm-aided (swing) CMJ height ($r = 0.56$, $p = 0.03$) (Chamari et al, 2008). SLJ has been used to evaluate lower limb performance in athletes, and a relationship between SLJ and sprint velocity was found ($r = 0.856$, $p < 0.01$) (Peterson et al, 2006); however, a simpler method is desirable for athletes to conduct self-assessments during times when the team could not train together, such as during the COVID-19 pandemic. The method used in this study to record SLJ is simple and can be conducted by individuals in small training spaces. Furthermore, even for a high school player, focusing on lower limb strength could lead to improved performance in the future. We ran a new angled COD test for handball players. To our knowledge, this study is the first to include a 20-m zigzag test at sharp angles of 45°

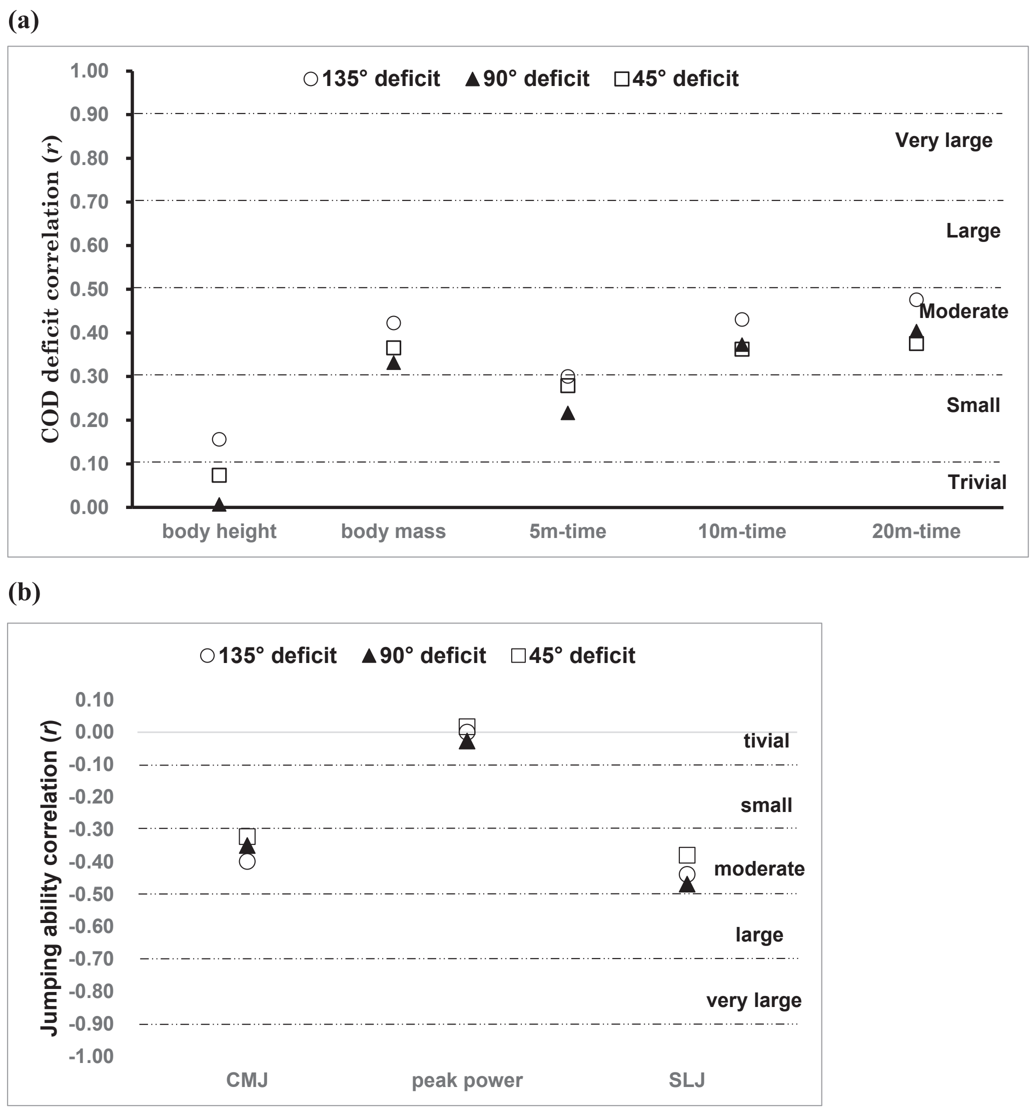

Fig. 4. (a) Relationship between zigzag test (COD) deficit time and other measurements. (b) Relationship between zigzag test (COD deficit) and jumping ability. COD, change of direction; CMJ, countermovement jump; SLJ, standing long jump.

(45° <90°) and 135°.

Previous studies have found a large correlation ($r = 0.56$, $p \leq 0.05$) between CMJ height and the zigzag test (Pereira et al, 2018) and a very large correlation ($r = -0.900$, $p < 0.01$) between SLJ and the agility test (T-test) (Peterson et al, 2006). In the present study, we also found a large correlation between CMJ and the zigzag test (135°, 90°, and 45°: $r = -0.607$, -0.594, and -0.613, respectively; $p < 0.01$). The strength of the correlation between the zigzag test deficit and CMJ height was found to be moderate (135°, 90°, and 45°: $r = -0.399$, -0.350, and -0.323, respectively; $p < 0.01$, 0.05, and 0.05; respectively). To the best of our knowledge, no previous studies have analysed the relationship between SLJ and the zigzag test. This present study found that the relationship between the zigzag test and SLJ was large (135°, 90°, and 45°: $r = -0.642$, -0.684, -0.658, respectively; $p < 0.01$). Furthermore, the relationship between COD deficit and SLJ was moderate (135°, 90°, and 45°: $r = -0.439$, -0.469, and -0.380, respectively; $p < 0.01$, $p < 0.01$, and $p < 0.01$, respectively).

In the study by Peterson et al (2006), the *t*-test included sprint, side-stepping, carioca stepping, and backward run, and the direction-change method involved sprinting forward while decelerating or side-stepping). The zigzag test requires changing direction by repeating acceleration and deceleration in the course. Despite these differences, the correlation analyses between COD and SLJ in Peterson et al's study and our present study show similar correlation coefficients (Peterson et al's study: $r = -0.613$; this study: $r = -0.642$ -0.684), probably because the sprint time has an effect when performing the direction change test in terms of time, rather than the COD deficit, as reported in a previous study (505-COD time and 30-m sprint time, $r = 0.70$, $p < 0.01$) (Nimphius et al, 2016). Accordingly, the relationships between SLJ and 5-, 10-, and 20-m sprint times were moderate to very large in the present study ($r = -0.44$, -0.65, and -0.73, respectively; $p < 0.01$). Therefore, the similarity in the strength of the association between the COD test and SLJ is due to the sprint time, despite the different direction change methods used in the study by Peterson et al (2006) (*t*-test) and the current study (zigzag test). This novel finding would provide a basis for future research.

Previous studies have measured COD at angles of 100° and 180° (Little et al, 2005; Nimphius et al, 2016). The relationship between COD and jumping ability is greatly dependent on the COD angle, and COD is more closely related to SLJ than the CMJ. In addition, COD ability is related to jumping ability, as noted in previous studies (Loturco et al, 2018; Pereira et al, 2018). A COD of 135° was related to jumping ability even after considering COD deficit, suggesting that lower limb strength, in addition to the COD technique, may be required at a sharper angle. In contrast, a COD of 45° deficit was not strongly associated with physical

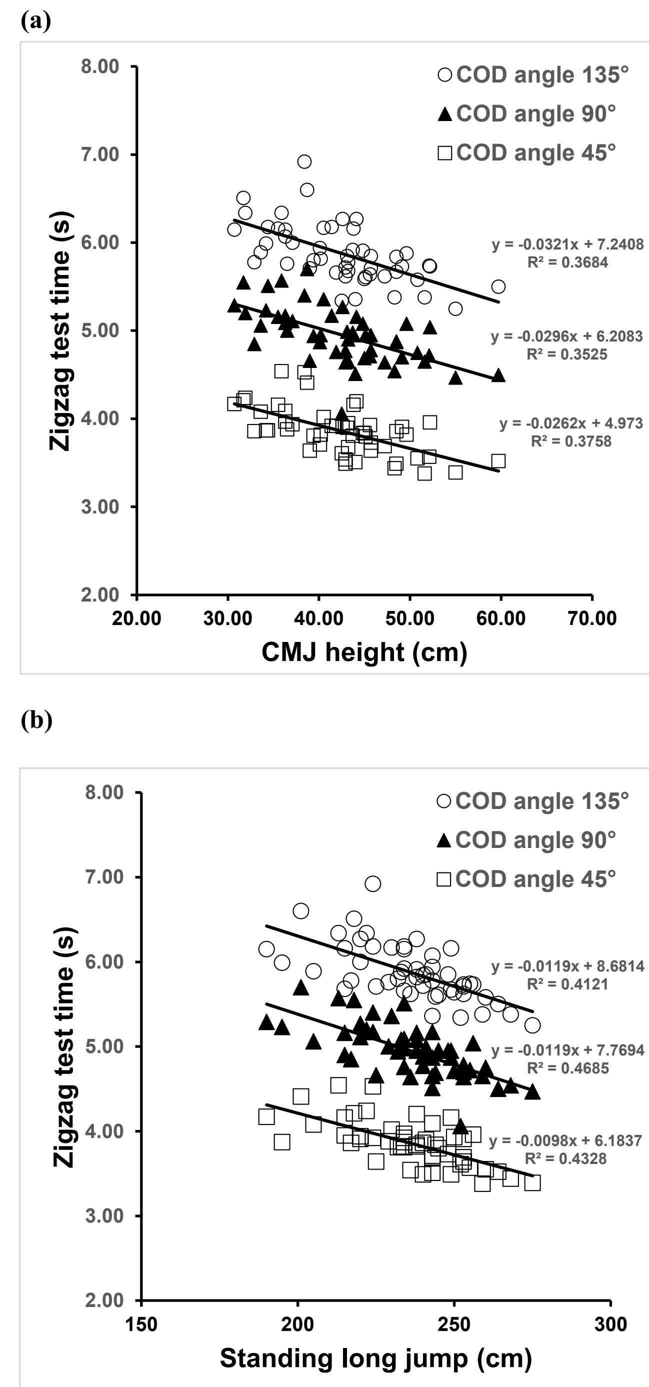

Fig. 5. (a) Relationship between zigzag test time and CMJ height ($n = 51$; 135°, 90°, and 45°: $r^2 = 0.3684$, 0.3525, and 0.3758, respectively; $p < 0.01$). (b) Relationship between zigzag test time and standing long jump ($n = 51$; 135°, 90°, and 45°: $r^2 = 0.4121$, 0.4685, and 0.4328, respectively; $p < 0.01$). COD, change of direction; CMJ, countermovement jump.

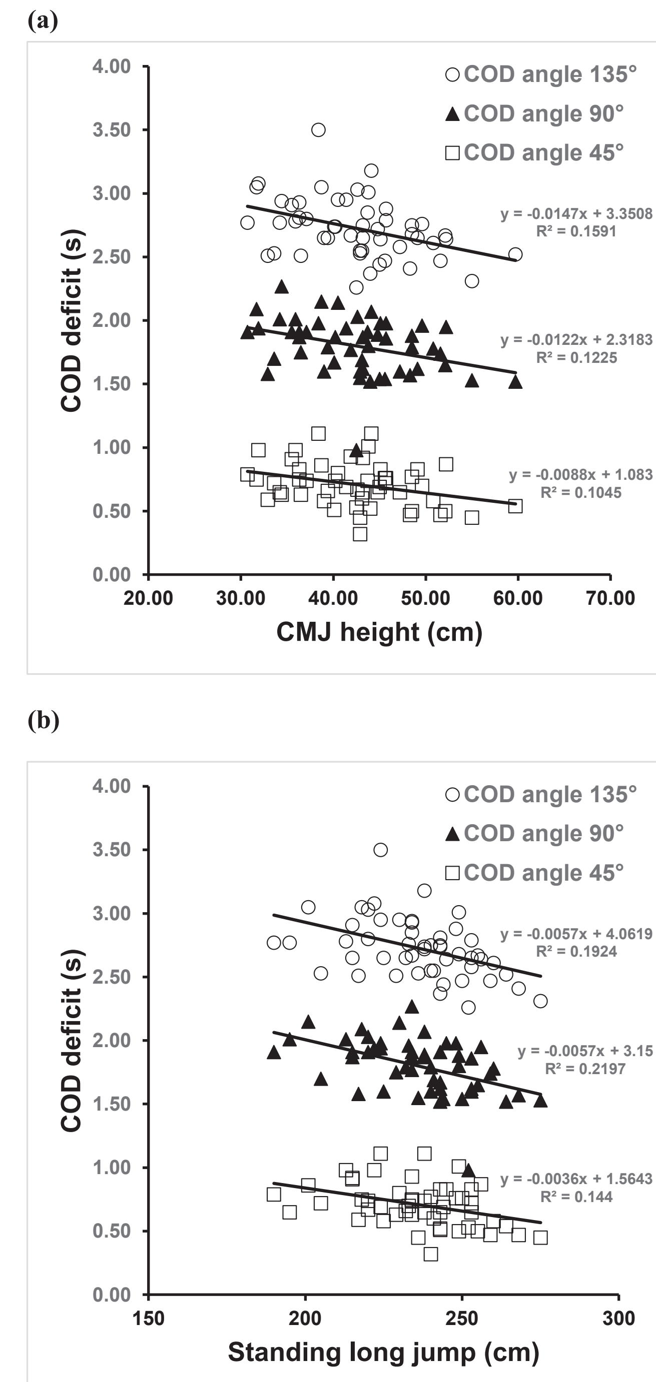

Fig. 6. (a) Relationship between zigzag test time deficit (COD deficit) and CMJ height ($n = 51$; 135°, 90°, and 45°: $r^2 = 0.1591$, 0.1225, and 0.1045, respectively; $p < 0.01$, 0.05, and 0.05, respectively). (b) Relationship between zigzag test time deficit (COD deficit) and standing long jump ($n = 51$; 135°, 90°, and 45°: $r^2 = 0.1924$, 0.2197, and 0.144, respectively; $p < 0.01$). COD, change of direction; CMJ, countermovement jump.

fitness, especially jumping ability.

Handball is a competitive sport that includes body contact, and an athlete's height and weight are important when evaluating performance, which may differ based on the athlete's court position (Michalsik et al, 2018). Therefore, in this study, we investigated the partial correlation among sprinting, jumping, and COD abilities after adjusting for BMI and found that BMI might be related to the above parameters. We also investigated the correlation between jumping and COD abilities when the sprinting ability was adjusted for and found that sprinting ability was related to COD, suggesting that a time-only test of an athlete's sprint ability may not accurately reflect the athlete's abilities. A 135° COD time and 135° COD deficit weakly correlated with peak power ($r = 0.282$ and 0.282, respectively; $p = 0.053$), suggesting that lower limb reactive strength, especially bilateral leg reactive strength (four changes 60° test: $r = -0.54$, $p < 0.05$), is related to a COD test; the result is consistent with previous findings (Young et al, 2002).

This study has some limitations. This study only included a specific

Table 4
Correlations among sprinting, jumping, and change of direction abilities after controlling for body mass index.

	Sprint ability			Jump ability		
	5-m sprint time	10-m sprint time	20-m sprint time	CMJ height	Peak power	SLJ
135° time	0.463**	0.657**	0.722**	−0.675**	−0.606**	−0.611**
90° time	0.420**	0.639**	0.694**	−0.659**	−0.640**	−0.662**
45° time	0.539**	0.699**	0.742**	−0.689**	−0.649**	−0.632**
135° deficit	0.124	0.298*	0.345*	−0.415**	−0.343*	−0.374**
90° deficit	0.036	0.237	0.266	−0.358 *	−0.356 *	−0.411**
45° deficit	0.109	0.223	0.228	−0.329 *	−0.302 *	−0.309*

*$p < 0.05$, **$p < 0.01$.
CMJ, countermovement jump; SLJ, standing long jump.

Table 5
Correlations among sprinting, jumping, and change of direction abilities after controlling for sprinting ability (5-, 10-, and 20-m sprint time).

	CMJ height	Peak power	SLJ
135° time	0.040	0.282	−0.036
90° time	0.090	0.262	−0.156
45° time	−0.023	0.199	−0.132
135° deficit	0.040	0.282	−0.036
90° deficit	0.090	0.262	−0.156
45° deficit	−0.023	0.199	−0.132

*$p < 0.05$.
CMJ, countermovement jump; SLJ, standing long jump.

group of athletes (handball players); therefore, these results may not be generalisable to other competitive athletes. Second, we only investigated the strength of the relationship (connection) between several measurement items. Therefore, further studies are needed to investigate the rate of force development, which is used to show the strength of the connection between the measurement items. Indeed, a strong jumping ability does not mean that it is directly linked to the COD test result, and improving jumping ability will not necessarily improve the COD ability; thus, each athlete's results should be interpreted in terms of technique, fitness, and ability. Particularly, in this study, the vertical CMJ was performed without using the recoil motion of the arms, while the SLJ was accompanied by a recoil motion of the arms, probably due to the different prevalence rates of the measurement methods. Although the method of vertical jumping without arm recoil is widespread, SLJ without arm recoil is not common. Further studies should be conducted to investigate the difference in jumping distances with and without the arm recoil motion. Based on our present findings, further studies are needed to use a regression equation to predict these abilities according to the relationship between SLJ and straight running measured in this study and the relationship between SLJ and zigzag test.

This study measured COD ability with a new zigzag test that has not been used previously. We found that the SLJ of elite handball players is strongly associated with their COD ability, suggesting that SLJ can be used as a substitute for CMJ. Sprinting ability is also strongly related to COD, and there is a significant correlation between 135° zigzag test and CMJ height, indicating that vertical jumping ability is related to sharp angle changes. Therefore, lower limb strength plays a role in COD ability at sharper angles.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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