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Research article

The relationship between performance and trunk movement during change of direction

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Abstract
The purpose of this study was to obtain the trunk kinematics data during a change-of-direction task and to determine the relationship between trunk kinematics and the change-of-direction performance. The design of this investigation was a descriptive laboratory study. Twelve healthy male collegiate soccer players (age: 21.3 ± 1.0 yrs, body mass: 67.7 ± 6.7 kg, and height: 1.75 ± 0.05 m) participated in this study. Participants performed a shuttle run cutting task with a 180 degree pivot as quickly as possible. The shuttle run cutting time, ground contact time during a change-of-direction, and trunk inclination angle were measured. The shuttle run cutting time tends to correlate positively with ground contact time. During the change-of-direction task, the trunk forward inclination angle gradually increased during the first 50% of the stance phase and decreased subsequently whereas the trunk flexed, maintaining a left inclination during the first 40% of the stance phase and changing exponentially in the opposite direction. Forward angular displacement of the trunk between foot-contact and maximum trunk inclination correlated positively with the shuttle run cutting time ($r = 0.61$, $p < 0.05$) and ground contact time ($r = 0.65$, $p < 0.05$). These findings suggest that the change-of-direction performance could be related to the small angular displacement of the trunk during a change of direction. Moreover, it was considered that there might be optimal inclination angles related to change-of-direction performance. Therefore, coaches in field sports should check body posture and trunk movements during changes of direction.

Key words: Kinematics, angular displacement, posture, stability, field sports.

Introduction

Changes of direction are required in many field sports, e.g., soccer, handball, and basketball. In a competitive game, soccer players make an average of 50 turns per game (Withers et al., 1982), and perform a total of 723 ± 203 turns and swerves during match-play (Bloomfield et al., 2007). Some researchers have stated that the ability to change direction while sprinting is a determinant of field sports performance (Sheppard and Young, 2006) or a prerequisite for successful participation in modern-day field sports (Brughelli et al., 2008). Moreover, the ability to change direction is a key factor in developing elite soccer players as it is the strongest predictor for talent identification (Reilly et al., 2000).

Some factors such as sprint speed, leg muscle qualities, and technique have been proposed as being related with the ability to change direction (Young et al., 2002). Many researchers have utilized correlational analysis or longitudinal training studies pertaining to sprint speed (Draper and Lancaster, 1985; Little and Williams, 2005; Shiokawa et al., 1998; Young et al., 2001; Vescovi and McGuigan, 2008) and leg muscle strength and power (Davis et al., 2004; Hoffman et al., 2007; Markovic et al., 2007; Markovic, 2007; McBride et al., 2002; Young et al., 2002). With regard to the change-of-direction technique, Young et al. (2002) proposed that one of the technical factors related to the change-of-direction performance is body lean and posture. Sheppard et al. (2006) also reported that the forward lean of the body or the postural adjustment technique played a key role in the performance of a change of direction. By reviewing research, they arrived at the conclusion that body lean and posture is important for change-of-direction performance. Nevertheless, these studies only proposed the factors that determined the agility performance from technical aspect; no data was presented regarding body lean and posture in relation to change-of-direction performance. Little research has been carried out on the relation between the factor of technique and the ability to change direction.

Biomechanical analysis is essential to evaluate performance in various sports. The main biomechanical measures of performance describe the kinematics (i.e., motion characteristics) or kinetics (i.e., force characteristics) of movement behavior. This biomechanical approach is ideal for the detailed analysis of the technique related to field sports performance (Carling et al., 2009). Some biomechanical studies (Dempsey et al., 2007; 2009; Houck, 2003; Patla et al., 1999;) have obtained data on trunk kinematics during the change-of-direction task so as to examine knee injury prevention; however they did not focus on the change-of-direction performance. Therefore, the purpose of this study was to determine the relationship between trunk kinematics during a direction change and the change-of-direction performance. We hypothesized that the change-of-direction technique assessed using trunk kinematics data would be correlated to the change-of-direction performance.

Methods

Subjects

Twelve healthy male collegiate soccer players (age: 21.3 ± 1.0 yrs; body mass: 67.7 ± 6.7 kg; height: 1.75 ± 0.05 m) participated in this study. All participants were free of lower extremity pain, history of serious injury or opera-

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tive treatment, or subjective symptoms, which could interfere with sports activities. The study was approved by the Faculty of Sport Sciences Ethics Committee, Waseda University. All subjects and, if necessary, their parents, received an explanation of all experimental procedures, and informed consent was obtained before the testing began. The investigations were conducted in accordance with the Declaration of Helsinki.

Experimental task

Following a standardized warm-up, subjects were required to perform the following shuttle run cutting task in an indoor experimental facility. Shuttle run cutting tasks were conducted under similar environmental conditions while wearing the same athletic running shoes (Adidas Response Cushion, Herzogenaurach, Germany). The subjects ran straight ahead for 5 m, planted their cutting foot on the force plate perpendicular to their initial direction of motion, and then changed direction to move 180 degrees to their initial direction of motion (Figure1). We used our original shuttle run cutting test with a 180-degree pivot in this study because of experimental spatial limitations, similar to the 505 test (Draper and Lancaster, 1985). The 505 test is a valid and reliable measure of an individual's ability to make a single direction change. This test has been used for national-level players (basketball, hockey, netball, and tennis) who need to be able to change directions skilfully and be agile (Ellis and Smith, 2000). Our original shuttle run cutting test was designed on the basis of the 505 test and placed great emphasis on measuring a player's ability to decelerate, change direction, and accelerate following a change of direction.

To comply with the experimental setting, they conducted this change-of-direction maneuver with their left limb. All subjects were right leg dominant and thus used this leg to kick the ball, whereas their left leg was used to support their body weight. Subjects were instructed to run at the maximum speed and to change direction as quickly as possible. They were allowed to perform several preparatory trials so as to understand the appropriate technique. Measurements were continued until three successful trials had been recorded; with at least 2 min rest provided between all efforts. If the subjects were unable to plant their foot perpendicularly or slipped during a direction change, the trials were excluded.

Data collection

To evaluate the change-of-direction performance, we measured shuttle run cutting time and ground contact time during the stance phase of the 180-degree direction change. In this study, stance phase was defined as the point when the cutting foot was planting on the force plate. Shuttle run cutting time was recorded using a wireless timing system (Brower Timing Systems, Utah, USA). The laboratory was equipped with a force plate (9287A; Kistler Japan Co., Ltd., Tokyo, Japan). Subjects were instructed to change direction by 180 degrees on the force plate. The vertical ground reaction force was used to calculate ground contact time. The force data was recorded at 1000 Hz.

An eight-camera high speed motion analysis system (Hawk; Motion Analysis Co., California, USA) was used to record the 3D kinematics of the trunk movements during the 180-degree direction change. The motion data was recorded at 200 Hz.

To collect the kinematic data, twelve reflective markers, 9 mm in diameter, were attached to subjects at the following landmarks and segments: the manubrium of the sternum, a spinous process of the second thoracic vertebra, both acromion processes, both midpoints of the clavicle, both anterior superior iliac spines, both posterior superior iliac spines, and both iliac crests. The placement of these markers was determined in a previous study using the point cluster technique (Chaudhari et al., 2005). We analyzed the kinematics data during the change-of-direction phase and normalized each ground contact time as a percentage.

Data analysis

The trunk segment was created on the basis of the coordinate data obtained from the markers. The attitude of the trunk segment was determined from the principal axis using the point cluster technique (Chaudhari et al., 2005; Andriacchi et al., 1998). The principal axes are eigenvectors of the inertia tensor matrix of cluster markers. By using a cluster system of skin markers, the point cluster technique presumes to cancel out the noise resulting from skin deformation. Previous studies have established the validity of the point cluster technique (Chaudhari et al., 2005; Andriacchi et al., 1998). We developed an algorithm of the point cluster technique by following the

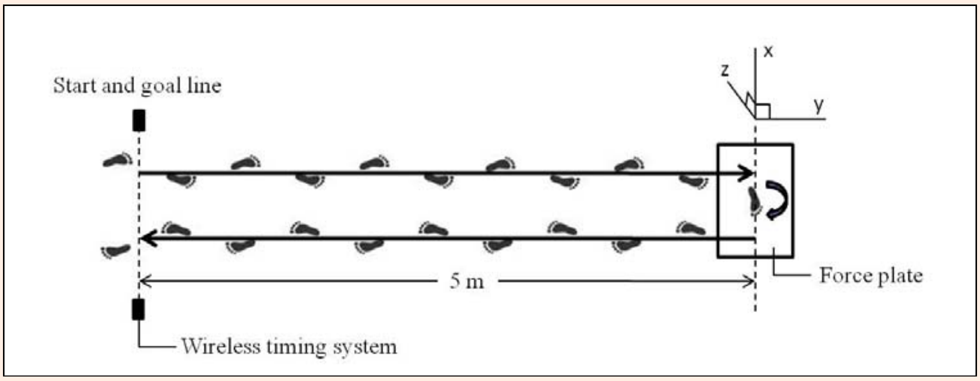

Figure 1. Diagram of the shuttle run cutting task. Participants ran straight ahead for 5 m, planted their cutting foot, and then changed direction to move 180 degrees to their original direction of motion.

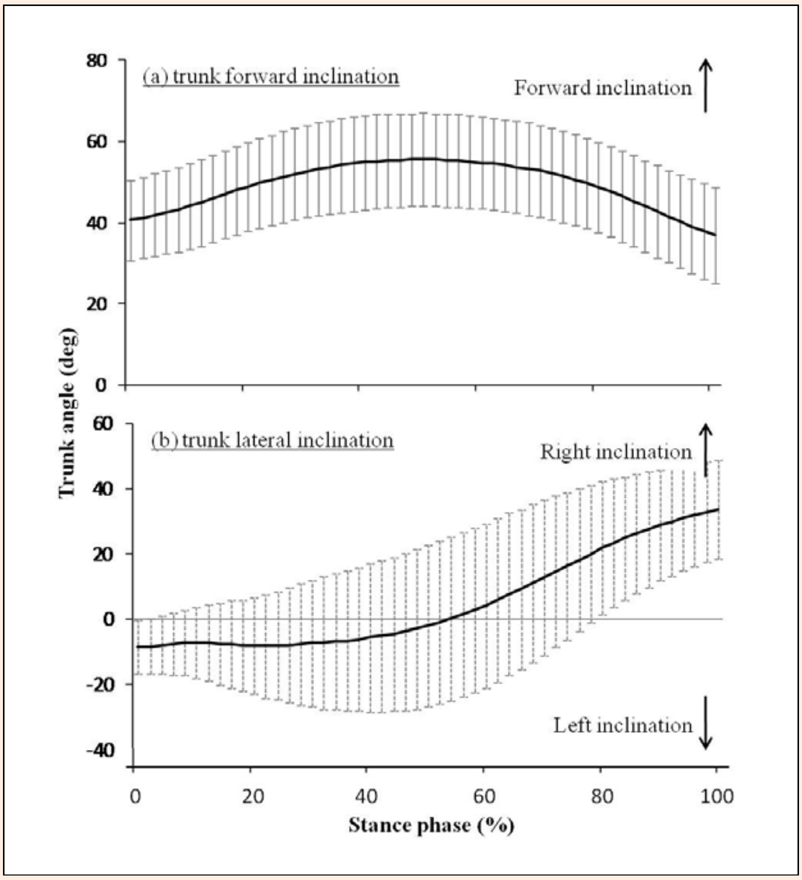

Figure 2. Average kinematics data of the trunk during change of direction. Data presented for trunk forward inclination (a) and trunk lateral inclination (b).

procedure described by Chaudhari et al. (2005) and Andriacchi et al. (1998) using IGOR Pro software (Wave Metrics Inc., Oregon, USA). Trunk inclination (trunk forward inclination and trunk lateral inclination) was defined for the long axis of the principal axis relative to the global axes. Trunk forward inclination was measured as the angle between the long axis of the principal axis of the trunk segment and the z–axis in the x–z plane (Figure 1), with positive values indicating the forward inclination of the trunk. Similarly, trunk lateral inclination was measured as the angle between the long axis of the principal axis of the trunk segment and the z–axis in the y–z plane (Figure 1), with positive values indicating right inclination and negative values indicating left inclination.

We analyzed the trunk inclination angle at the time of foot-contact, maximum inclination of trunk, and foot-off. Moreover, we calculated the angular displacement of the trunk inclination between the minimum and maximum peaks during the following two phases: (A) between the foot-contact and maximum inclination of trunk and (B) between the maximum inclination of trunk and foot-off. All dependent variables were calculated for each trial and were then averaged across the three trials.

Statistical analysis

All the data is expressed as mean ± standard deviation. The relationships between the shuttle run cutting time, ground contact time, trunk inclination angle, and trunk angular displacement were determined by Pearson's product-moment correlation coefficient. All statistical procedures were performed using SPSS software (ver. 14.0 for Windows), and the statistical significance of all tests was set at $p < 0.05$.

Results

Table 1 presents the change-of-direction performance using two parameters. Figure 2 illustrates the time-course changes in the angle of trunk inclination during a change of direction. In the sagittal plane, the trunk forward inclination angle gradually increased during the first 50% of the stance phase and subsequently decreased. In the frontal plane, the trunk flexed, maintaining left inclination during the first 40% of the stance phase and changing exponentially in the opposite direction.

Table 1. Change of direction performance results. Data are means (±SD).

Shuttle run cutting time(s)	2.62 (.06)
Ground contact time during change of direction(s)	.44 (.07)

Table 2 lists the trunk inclination angle at characteristic periods during a change of direction. Table 3 presents the trunk angular displacement during two phases. Table 4 summarizes the relationships between the shuttle run cutting time and trunk inclination angle and between the ground contact time and trunk inclination angle, respectively. Figure 3 depicts the relationships between the shuttle run cutting time and lateral inclination angle of the trunk at maximum inclination. Table 5 presents the relationships between the shuttle run cutting time and trunk angular displacement and between the ground contact time and trunk angular displacement, respectively. The trunk inclination angle at each time period did not correlate with shuttle run cutting time or ground contact time (Table 4). The trunk forward angular displacement between foot-contact and maximum inclination of the trunk was moderately and positively correlated with the shuttle run cutting time (r = 0.61, $p < 0.05$) and ground contact time (r = 0.65, $p < 0.05$) (Table 5).

Table 2. Results of trunk inclination angles (°) during a change of direction. Data are means (±SD).

Forward inclination angle at foot-contact	40.6 (9.8)
Forward inclination angle at maximum inclination	56.4 (11.6)
Forward inclination angle at foot-off	36.9 (11.9)
Lateral inclination angle at foot-contact	−6.8 (7.8)
Lateral inclination angle at maximum inclination	−14.4 (14.4)
Lateral inclination angle at foot-off	33.8 (15.2)

Table 3. Results of trunk angular displacement during a change of direction. (A) indicates the period between foot-contact and maximum inclination of trunk. (B) indicates the period between maximum inclination of trunk and foot-off. Data are means (±SD).

Forward angular displacement during (A) (°)	16.0 (8.8)
Forward angular displacement during (B) (°)	19.5 (7.1)
Lateral angular displacement during (A) (°)	6.6 (8.3)
Lateral angular displacement during (B) (°)	48.1 (14.5)

Discussion

The primary purpose of this study was to determine the relationship between trunk kinematics during a direction change and change-of-direction performance.

The results pertaining to the change-of-direction performance are presented in Table 1. The shuttle run cutting time was an average of 0.1 to 0.3 s slower than that in previous studies using the 505 test (Draper and Lancaster, 1985; Ellis and Smith, 2000). The reason for this difference is that in the 505 test, the sprint time with change of direction was measured when the subject reached a high speed through a 10 m pre acceleration before the change-of-direction task. We also investigated ground contact time as one of the parameters in the change-of-direction performance. Only one study has reported ground contact time during various changes-of-direction tests (Shiokawa et al., 1998). Shiokawa et al. (1998) found a small correlation between the zigzag agility test time and ground contact time during direction changes (r = 0.44, $p < 0.05$). The result of this study also showed a correlation between shuttle run cutting time and ground contact time (r = 0.52, $p = 0.08$); this supports Shiokawa's data. It is expected that shorter ground contact time is important for the change-of-direction performance. Young et al. (2002) reported small to moderate correlations between the change-of-direction test time and unilateral reactive strength, which is required for shorter ground contact time during drop jump (r = −0.23 to −0.71). They discussed that reactive strength was similar to the push-off mechanism during the change of direction. It is thus evident that ground contact time influences the change-of-direction performance.

In the change of direction during shuttle run cutting, subjects demonstrated a forward-inclined trunk during the first 50% of the stance phase and a left-inclined trunk during the first 40% of the stance phase (Figure 2). Change of direction is a maneuver that is a combination of deceleration and acceleration for changing direction (Ellis and Smith, 2000; Neptune et al., 1999; Shiokawa et al., 1998); this requires a braking force followed by a propulsive force (Brughelli et al., 2008). Neptune et al. (1999) have suggested that the body's center of mass is decelerated after impact and that the knee is extended during the propulsion phase (> 50% of the stance phase) on the basis of electromyography (EMG) and kinematics data obtained during side-cut and v-cut movements. In this study, therefore, subjects would decelerate so as to apply a braking force until 40 to 50% of the stance phase was reached and would then accelerate, gradually creating propulsion after 40 to 50% of the stance phase.

To evaluate the relationships between change-of-direction performance and trunk kinematics in relation to the change-of-direction technique, the trunk inclination angle at three periods (foot-contact, maximum inclination of trunk, and foot-off) and trunk angular displacement during two phases (between foot-contact and maximum inclination of trunk and between maximum inclination of trunk and foot-off) were used in this study. The point of foot-contact, maximum inclination of trunk and foot-off are considered characteristic periods for assessing each change-of-direction task. The results pertaining to the trunk inclination angle and the trunk angular displacement are presented in Tables 2 and 3. Sheppard et al. (2006) have suggested that forward lean and a low center of gravity were essential in optimizing acceleration and deceleration. In this study, subjects changed direction with a forward inclination of 56.4° ± 11.6° on an average and a lateral inclination of −14.4° ± 14.4° on an average at maximum inclination of trunk (Table 2). All subjects belonged to a top-level collegiate soccer team in Japan. Therefore, these data provide basic information regarding

Table 4. Correlations between change-of-direction performance and trunk inclination angle at the time of foot-contact, maximum inclination of trunk, and foot-off.

Trunk movement		Shuttle run cutting time		Ground contact time	
		r	*p* value	r	*p* value
Forward inclination angle	Foot-contact	−.10	.75	−.32	.31
	Maximum inclination	.39	.20	.24	.45
	Foot-off	.04	.90	−.01	.96
Lateral inclination angle	Foot-contact	−.26	.42	−.21	.52
	Maximum inclination	−.50	.10	−.47	.12
	Foot-off	.07	.83	−.12	.71

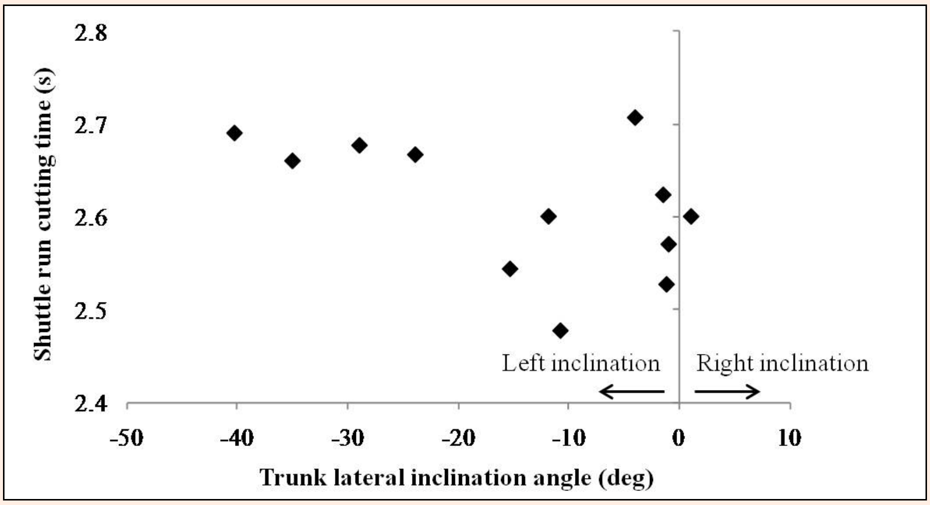

Figure 3. Relationships between shuttle run cutting time and lateral inclination angle of the trunk at maximum inclination.

the change of direction movement and will be useful for coaches or practitioners in terms of providing instruction regarding the optimal posture during a change of direction.

The trunk inclination angle at the three periods and shuttle run cutting time, as well as the trunk inclination angle at the three periods and ground contact time, were not all correlated at statistically significant levels (Tables 4, respectively). These results suggest that the trunk inclination angle of each period does not relate to the change-of-direction performance. However, both excessive right inclination and excessive left inclination of the trunk tended to delay shuttle run cutting time (Figure 3). These findings suggest that a range of optimal angles of trunk inclination may exist. A possibility is exists that a left inclination of the trunk of approximately 10° at the time of maximum inclination is the optimal angle for the change-of-direction performance in this study.

Shuttle run cutting time correlated moderately and positively with the trunk forward angular displacement between the foot-contact and maximum inclination of the trunk ($r = 0.61$, $p < 0.05$) (Table 5). Furthermore, ground contact time and forward angular displacement between the foot-contact and maximum inclination of the trunk was correlated positively at a moderate level ($r = 0.65$, $p < 0.05$) (Table 5). These data suggest that trunk stability during a change of direction is an important factor in the change-of-direction performance. Previous studies have discussed the importance of postural assessment involving trunk movement. Sheppard et al. (2006) proposed that the change of direction during sprinting required postural adjustments. Markovic (2007) also reported that changing directions during agility tasks required the maintenance of body balance. Moreover, some authors have suggested that trunk displacement occurs while changing directions to offset through postural adjustment to control the center of mass (Houck, 2003; Patla et al., 1999). Core and trunk stability maximize all the kinetic chains of upper and lower extremity functions (Kibler et al., 2006). As such, the adjustment of posture and maintenance of body balance are necessary for a change of direction. Therefore, the small forward angular displacement of the trunk while changing directions, as noted in this study, is related to the change-of-direction performance from a technical perspective.

In change-of-direction maneuvers, the preparation that goes into the stance phase may be considered as a factor affects the trunk inclination angle or angular displacement during a change of direction. Young et al. (2002) proposed that the adjustment of strides to accelerate and decelerate is also related to the change in direction speed. Although we suggest that the preparation phase will be very important for a change-of-direction performance, we can not present supportive data for the same from this study. Further research is needed to investigate the relationship between the preparation that goes into the stance phase and change-of-direction performance or the trunk movement during the stance phase defined in this study.

Practical applications

Field sports players are required to engage not only in straight-line movements but also in multidirectional movements, including direction changes. Given this fact, coaches on the field have taken various physical and

Table 5. Correlations between change-of-direction performance and trunk angular displacement. (A) indicates between foot-contact and maximum inclination of trunk. (B) indicates between maximum inclination of trunk and foot-off.

Trunk movement		Shuttle run cutting time		Ground contact time	
		r	*p* value	r	*p* value
Forward angular displacement	During (A)	**.61 ***	**.04**	**.65 ***	**.02**
	During (B)	.57	.06	.41	.18
Lateral angular displacement	During (A)	.45	.14	.42	.17
	During (B)	.49	.11	.32	.31

* $p < 0.05$

physiological approaches to improve change-of-direction and agility performance. To enhance change-of-direction performance, training that involves sprinting with direction changes (i.e., change-of-direction tests themselves) is necessary (Brughelli et al., 2008). Accordingly, it is very important for coaches to consider the factors that determine a good change-of-direction performance.

The findings of this study indicate that the small forward angular displacement of the trunk during a direction change is related to the change-of-direction performance. Moreover, it is considered that optimal angles of trunk inclination related to change-of-direction performance might exist. Therefore, coaches in field sports should check the body posture and trunk movement of players when they require a change of direction or when they participate in sport-specific change-of-direction training, as improvements in the change-of-direction technique may lead to players being able to make these changes more rapidly.

There are several limitations to this study. We assumed that the small angular displacement of the trunk was related to the change-of-direction ability and performance; however, we analyzed only trunk kinematics. To improve our understanding of the change-of-direction technique, additional analyses such as those of kinematics, kinetics, and muscle activation, including other joints, are required. The statistical power is also somewhat low because of the small sample size (n = 12) in this study. In the future, it is our intention to continue to collect kinematics data pertaining to trunk movement during a change of direction.

The experimental design of this investigation was that of a cross-sectional study. Interventional research that implements change-of-direction training is necessary for investigating change-of-direction performance and trunk stability. Moreover, different types of change-of-direction tasks must be studied in this regard.

Conclusion

This study provides important data pertaining to trunk kinematics during change of direction and suggests a change-of-direction technique that is related to the change-of-direction performance. The trunk inclination angle at the time of foot-contact, maximum inclination, and foot-off were not correlated with the change-of-direction performance, whereas the forward angular displacement of the trunk between foot-contact to maximum inclination correlated moderately with shuttle run cutting time and ground contact time. These findings suggested that change-of-direction performance may be related to the small angular displacement of the trunk during direction changes. Moreover, it was considered that there might be optimal inclination angles related to change-of-direction performance.

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Key points

- Small forward angular displacement of the trunk during a direction change is related to the change-of-direction performance.
- Trunk stability during a change of direction is an important factor in the change-of-direction performance.
- There might be a range of optimal angles of trunk inclination during a change of direction.
- Coaches in field sports should check the body posture and trunk movement of players when they require a change of direction or when they participate in sport-specific change-of-direction training.

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