The Role of the Trunk Control in Athletic Performance of a Reactive Change-of-Direction Task

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Abstract

Edwards, S, Austin, AP, and Bird, SP. The role of the trunk control in athletic performance of a reactive change-of-direction task. *J Strength Cond Res* 31(1): 126–139, 2017—Agility is vital to success in team sport competition with the trunk argued to play a key role in sport performance. This study explored the role of trunk control during a reactive change-of-direction task (R-COD) and field-based measures of athletic performance. Twenty male players completed field-based athletic performance assessments (modified Illinois agility test [mIAT], 3 repetition maximum back squat, and 5 countermovement jumps [CMJ]) and R-CODs, during which 3-dimensional ground reaction forces and kinematics were recorded. Trunk control was assessed as the sum of the trunk relative to the pelvis range of motion (ROM) in all 3 planes during the R-COD. Participants with the highest (HIGH, $n = 7$) and lowest (LOW, $n = 7$) trunk ROM values were grouped. The HIGH group achieved significantly shorter mIAT time duration, higher CMJ height, and lower knee flexion angles, greater trunk lateral flexion and rotation relative to pelvis, and greater angular momentum during the R-COD compared with the LOW group. Superior athletic performance was associated with decreased trunk control (high trunk ROM) during the R-COD. Although this study suggested that trunk control is a vital component of performance, it is unknown whether this trunk control is inherent or an effect of training history, nor does not support current optimal athletic performance recommendation of decreased trunk motion during R-COD.

Key Words sidestepping, biomechanics, lumbopelvic, agility

Introduction

A critical aspect of field and court sport performance is agility that requires athletes to decelerate, quickly reorientate the body in a new direction, and rapidly accelerate in response to game conditions and strategic and tactical demands (38). It is theorized that the core operates to form a link between the upper and lower limbs by controlling posture and force interplay across the musculoskeletal system (6). Previous research has poorly defined the "core" and described it using ambiguous terms dependent on the context of the research (14,19,44), such as trunk, core, lumbar region, low back, lumbopelvic region, and lumbopelvic hip complex. The lack of clear terminology and well-defined concepts makes selection of valid assessment tools difficult, increasing the risk of methodological error and possibly contributing to the lack of a gold standard assessment tool being developed (14). Therefore, the term "trunk control" previously used to investigate trunk mechanics during a reactive change of direction (R-COD) (18–20) will be used from here on. It is defined according to Zazulak, Cholewicki, and Reeves (44) as "the capacity of the body to maintain or resume a relative position (static) or trajectory (dynamic) of the trunk after perturbation."

Bergmark (6) proposed that force is imparted via structures of the trunk that work together to control posture, maintain stability, and distribute force across the system. Stability is maximized by the motor control system through the coordinated cocontraction of musculature that must preserve stability by maintaining a balanced tension acting on the system at a given moment in time (26,28). Loss of tension within the trunk may cause the trunk to buckle; as such, synchronization of muscle activity across the system is vital to maintain stability (28,29). A strategy adopted by the trunk during high loading is to increase stiffness of the spine through cocontraction of core musculature via minimizing excess motion during motions, such as weight training, power lifting and strongman events (29), and agility tasks (35).

To optimize agility performance, it has been recommended that athletes need minimal pelvis tilt (25) and trunk flexion range of motion (ROM), to flex their trunk (35,38),

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to reorientate their trunk and pelvis toward the direction of travel (35). By adapting a trunk flexion posture, it is thought to optimize acceleration and deceleration characteristics (35,38) and lower the athletes' center of mass (39) to enable the athlete to apply more force in the intended direction of travel (42). Furthermore, faster agility performance has also been associated with greater thorax rotation toward direction of anticipated 75° cut (25).

Evidence on improving athletic performance from training studies supports the suggestion that a strong and stable trunk is conflicting, with correlations between performance and core assessments only ranging from weak to moderate (19,31,40). Clinical assessments of the core have used endurance as a correlate of control because of the correlation of lower-back pain with decreased endurance times and core musculature weakness for static postures (32), such as those used in the McGill protocol (27). Although endurance is a critical aspect of performance in a number of sporting events, assessing the endurance of the trunk musculature is unlikely to give a clear indication of an athletes' ability to absorb, transfer, control, or dissipate forces acting on or through the body during agility movements. Assessments of core power previously described in research (31,40) using medicine ball throws from static and non–sport-specific postures may be reliable; however, the validity of such tests to dynamic field and court sport environments, in which athletes are in motion, may be questionable.

The cut task, a frequent performance agility movement in sport, has high validity for team sports and has previously been used to assess the influence of the absolute trunk segment relative to the global coordinate system motion on injury (11,20,30) and athletic performance (12,25,35). Nevertheless, this absolute trunk angle does not take into account the orientation of the pelvis nor whether the participant is running in a straight line, both of which may affect the magnitude of the absolute trunk angle. Furthermore, field-based assessments of athletic performance have reported conflicting between-study differences between agility performance and the back squat (21,42), countermovement jump (CMJ) height (13,36), and sprinting (36).

Therefore, the aim of this study is to explore the role of trunk control during an R-COD with a defensive opponent with field-based measures of athletic performance. It is hypothesized that participants displaying higher trunk control (low trunk ROM) during an R-COD with a defensive opponent will display superior performance in field-based measures of athletic performance compared with those participants displaying lower trunk control (high trunk ROM).

Methods

Experimental Approach to the Problem

The experimental protocol involved 3 sessions, a familiarization session of the performance session, followed by, in any order, a performance session and a biomechanical session. The performance session included a modified Illinois agility test (mIAT), 3 repetition maximum (3RM) back squat, core endurance tests, and static control tests, and the biomechanical session included a CMJ and an R-COD with a defensive opponent. Each participant performed the biomechanical and the performance sessions at the same time of the day, but there were between-participant differences in the time of day they each performed their sessions.

Subjects

Twenty male team sport athletes (age range 19–27 years) with no history of previous traumatic lower-limb injury requiring surgery were recruited (mean age = 21.6 ± 2.1 years; height = 183.2 ± 5.9 cm; mass = 89.9 ± 13.7 kg). Participants' dominant lower limb was identified as the limb contacting a ball during kicking, as it was the preferred lower limb used to change of direction. Written informed consent was obtained from each participant before data collection, and all methods were approved by the institutions' Human Research Ethics Committee.

Performance Session

Participants performed 3 trials of an mIAT with 5 minutes of self-paced waking recovery between (fastest recorded), which required the participant to complete the Illinois agility test course (1) twice. For the 3RM back squat test, an Olympic barbell was loaded with 50% of the reported history 1RM squat load of the participant, rounded to the nearest 10 kg increment. With each successful 3RM trial, as defined according to Baechle, Earle, National and Conditioning (3), the load was increased between 5 and 20 kg based on observation of the participants' effort of the previous lift, until a successful maximum 3RM was reached by the participant.

As per the protocol developed by McGill et al. (27), the core endurance tests involved the participant adopting 1 of 4 individual static postures once and to hold the static posture as long as possible with 5 minutes rest between tests. These postures in order included back extension, flexor endurance test, left side bridge, and right side bridge (Figure 1). Each test was timed and terminated by the tester when the correct posture specific to each individual test could no longer be maintained by the participant.

Using a NeuroCom Balance (VSR SPORT; NeuroCom International, Clackamas, OR, USA), each participant's static control was assessed by performing a stability evaluation test and limits of stability test. Stability evaluation test was used to assess an individual's postural sway velocity during double-, tandem, and single-limb stance positions. Limits of stability assessed the ability of the participant to accurately and quickly voluntarily move their center of gravity location to 8 predetermined targets without losing balance (7).

Biomechanical Data Collection

Passive reflective markers were attached to each participant's skin on the torso, pelvis, and lower limbs and the shoe (23). To avoid passive marker concealment, participants wore minimal clothing and their own socks and athletic shoes during trials. Participants then completed 5 minutes of self-paced warm-up

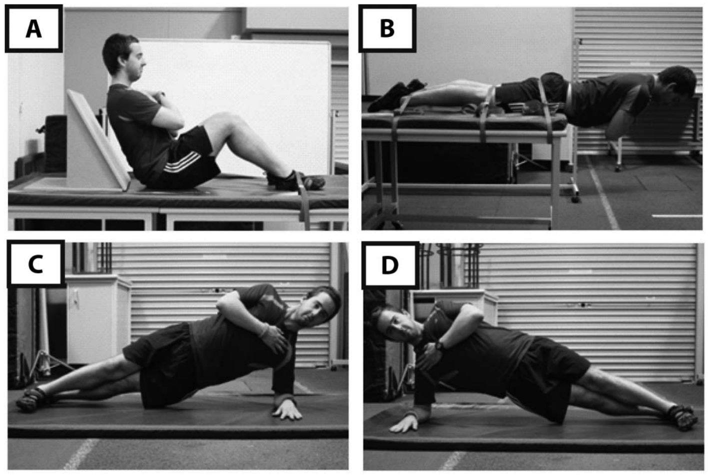

Figure 1. McGill protocol core stability endurance test postures for (A) flexion, (B) extension, (C) left side bridge, and (D) right side bridge hold.

on a cycle ergometer at 1.5 kp (Monark Model 828E; Monark, Varburg, Sweden) and 5 successful CMJ trials, followed by 5 successful trials of both left and right unanticipated cut tasks with a defensive opponent. For both the CMJ and the R-COD, 3-dimensional trunk and lower-limb kinematics were captured (250 Hz) using an 8 camera Oqus 300 motion system (Qualisys AB, Göteborg, Sweden) and the ground reaction force (GRF) data were recorded using 2 multichannel force platforms with inbuilt charge amplifier (Type 9281CA and Type 9281 EA; Kistler, Winterthur, Switzerland) embedded in the laboratory floor and fitted with an all-weather polyurethane running track material and connected to 2 control units (Type 5233A; Kistler).

Experimental Task

Participants were instructed to perform the CMJ by jumping vertically as high as possible and were permitted 1 preparatory downward swinging motion of the arms and torso before launching vertically upward with an upward swinging motion and arms extended overhead. A successful CMJ trial was defined as the participant launching and landing with each foot wholly contacting separate force platforms. Countermovement jump height was calculated as the difference between the location of the center of mass when standing and the maximal height reached during the CMJ.

An R-COD (unanticipated cut task with a defensive opponent) involved participants starting from a line marked 7 m from the front edge of the force platform and running toward the dual force platforms with an approach speed of between 4.5 and 5.5 $m \cdot s^{-1}$ (Speed Light; Swift Sports Equipment, Lismore, Australia). On the participants' approach to the force platforms, a signal was given manually by the author (AA) from either a red or green light directing the participant to either a left or right COD direction, in a randomized order. The participant reacted to the signal, performing a change of direction, stepping off the force platforms between lines marked on the floor at 30° and 60° from the axis of the running track, and originating at the midpoint of the force platforms' medial borders. A plastic skeleton was situated 40 cm from the rear edge of the force platforms to mimic a defending player in a game environment. Completion of a successful R-COD trial required a participant to achieve the required approach speed, the foot of the support limb wholly contacting only on one or both force platforms, the contact limb being the opposite limb to the new direction of travel, and the cut in the direction of the corresponding light-emitting diode signal with the swing limb passing behind the support limb. To minimize the effects of fatigue, participants were given a 1-minute rest between each trial and a 5-minute rest between each set of 20 trials (number of trials required to obtain successful trials: LOW, 89 ± 30; range, 41–143; HIGH, 73 ± 28; range, 31–100).

Data Reduction and Analysis

Using a customized LabView (2010; National Instruments, Austin, TX, USA) software program, a fourth-order zero-phase shift Butterworth digital low-pass filter was used to filter raw GRF data ($f_c = 50$ Hz) before calculating the individual GRF variables. Analysis of the kinematic and joint kinetic data was performed using Visual 3D software (version 4; C-Motion, Rockville, Maryland, USA). The raw kinematic coordinates, GRFs, free moments, and center of pressure data were filtered with a fourth-order zero-phase shift Butterworth digital low-pass filter ($f_c = 18$ Hz), before calculating individual joint kinematics and internal joint moments. Segmental mass and inertial property definition procedures are outlined in Mann, Edwards, Drinkwater and Bird (23).

All segments were defined as x-axis mediolateral, y-axis anterior-posterior, and z-axis up-down direction to conserve Cartesian local coordinate system sign conventions. All intersegmental joint angles were expressed using an xyz Cardan sequence of rotation. The net internal joint moments were normalized in accordance with the participants' body mass to account for participants' variations. Calculated GRF impulse values were also normalized to participants' body weight. Using the 18-Hz filtered kinetic data, the weight acceptance (WA) phase was defined from initial foot-contact

(IC) when the vertical GRF exceeded 10 N to the first local minimum (F_{WA}) after the first peak vertical GRF (F_{V1}) (11). The propulsion phase (PP) was defined from F_{WA} to toe-off (TO), during which the second peak vertical GRF (F_{V2}) occurred. The vertical GRF data were used to calculate temporal events (IC and at the times of F_{V1}, F_{WA}, F_{V2}, and TO). Loading rate of F_{V1} (LR F_{V1}, body weight per second) was calculated by dividing F_{V1} by the time interval between IC and the time of F_{V1}. For each of the 5 successful cut trials, the kinematic and kinetic variables that were calculated were as follows: Kinematic variables including ankle, knee, hip, L5-S1, and T12-L1 joint kinematics at IC and at the times of F_{V1}, F_{WA}, F_{V2}, and TO, and location of the center of gravity relative to the foot were calculated. Kinetic variables included the peak net internal ankle, knee, hip, L5-S1, and T12-L1 joint moments that were identified between IC and TO, the angular momentum of the model center of gravity at IC, TO, and the peak, and change in angular momentum during the WA phase and PP. Previous research on the kinematics and kinetics during a COD task have shown excellent reliability of the majority of the trunk and lower-limb kinematics and fair to good for most GRFs and knee and hip joint moments (25). Although data for both lower limbs were recorded, only the data for the COD directions that used the dominant lower limb as the support limb were used for analysis purposes.

Statistical Analyses

Trunk control during the R-COD was assessed as the sum of the ROM of the trunk relative to the pelvis from IC to TO in all 3 planes. The participants were ranked in order based on their trunk control and categorized into a higher ROM group (HIGH, $n = 7$) and a lower ROM group (LOW, $n = 7$, Figure 2). The middle ROM group ($n = 6$) was removed from the analysis to ensure a significant between-group difference in total trunk relative to pelvis ROM during the R-COD.

Mean and *SD* were calculated for each outcome variable for participants in the HIGH and LOW groups for each kinetic and kinematic variable during the R-COD, peak CMJ height, mIAT, 3RM squat, and McGill protocol total and individual tests. After confirming normality with a Kolmogorov-Smirnov test with Lilliefors correction, the data were analyzed using a series of independent samples *t*-tests ($p \leq 0.05$) to identify any significant between-group differences in the outcome variables. Granting there is an increase in likelihood of incurring an error because of multiple statistical comparisons being conducted, adjustment to the alpha level was deemed unnecessary because of the exploratory nature of the present study (34). Furthermore, the precision of estimation (95% confidence limit) and magnitude-based inferences (effect sizes, 8) were calculated to redress the deficiencies of null hypothesis significance testing–based research (16). Effects were defined as unclear when confidence limits exceeded the change in mean, being the small effect size threshold, of the *SD* on both sides of the null. Moderate or large effect sizes were defined as substantial (16). The precision of estimates is indicated by 95% confidence limits, which define the range representing the uncertainty in the true value of the sample mean. Approximately one-third of the sample size on those based on hypothesis testing is required when using a Bayesian approach (4), and therefore, a minimum of 7 participants per group were estimated based on our previous research. A customized Excel spread sheet was used for all statistical procedures (15).

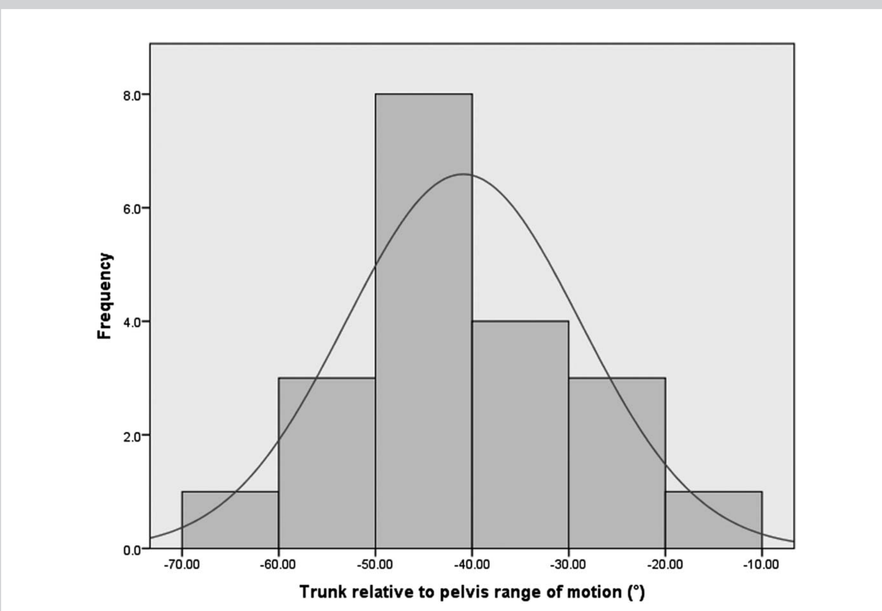

Figure 2. Normative distribution of the variable trunk control during stance phase of a reactive change-of-direction task.

Results

Field-Based Performance Variables

The HIGH group recorded significantly faster mIAT and higher CMJ height in comparison with the LOW group (Table 1). No significant differences in the control evaluation tests were observed during any stance position in either the firm or the foam surface. The limits of stability test were the HIGH group displayed faster velocity during diagonal backward and dominant side direction but

TABLE 1. Mean ± *SD* of the field-based measures of performance for the HIGH and LOW trunk control groups.*†

Variable	LOW	HIGH	d_a	CL	p
Age (y)	21.3 ± 1.9	22.1 ± 1.8	0.47	2.1	0.40
Height (cm)	1.84 ± 0.06	1.81 ± 0.05	0.63‡	6.4	0.26
Body mass (kg)	91.4 ± 15.8	87.4 ± 14.3	0.27	17.6	0.63
mIAT (s)	38.9 ± 2.1	36.9 ± 2.9	0.93§	2.9	0.01‖
3RM squat absolute (kg)	100 ± 24	106 ± 29	0.22	32	0.78
3RM squat relative	1.11 ± 0.26	1.21 ± 0.29	0.36	0.32	0.52
Countermovement jump (cm)	46 ± 8	58 ± 8	1.44§	10	0.02‖
McGill protocol					
Flexion (s)	123 ± 58	168 ± 116	0.77‡	107	0.42
Extension (s)	112 ± 41	98 ± 32	0.37	43	0.36
Left flexion (s)	85 ± 19	89 ± 31	0.25	30	0.62
Right flexion (s)	89 ± 23	92 ± 34	0.14	34	0.78
Total (s)	409 ± 108	446 ± 181	0.34	174	0.60
Stability evaluation					
Firm surface					
Double-limb stance ($°\cdot s^{-1}$)	0.67 ± 0.16	0.80 ± 0.39	0.44	0.35	0.44
Tandem stance ($°\cdot s^{-1}$)	1.78 ± 0.88	1.86 ± 0.58	0.10	0.87	0.86
Single-limb stance ($°\cdot s^{-1}$)	1.27 ± 0.38	1.40 ± 0.46	0.31	0.49	0.58
Foam surface					
Double-limb stance ($°\cdot s^{-1}$)	1.83 ± 0.53	1.99 ± 0.40	0.34	0.55	0.54
Tandem stance ($°\cdot s^{-1}$)	3.50 ± 0.63	3.53 ± 0.91	0.04	0.91	0.95
Single-limb stance ($°\cdot s^{-1}$)	3.74 ± 1.60	3.86 ± 1.31	0.08	1.70	0.89
Limits of stability					
Forward					
Maximum excursion (%)	98 ± 7	90 ± 10	0.84§	10	0.12
End point excursion (%)	85 ± 13	72 ± 17	0.86§	17	0.11
Velocity ($°\cdot s^{-1}$)	3.7 ± 1.6	4.6 ± 1.6	0.58‡	1.9	0.29
Diagonal (forward and dominant side)					
Maximum excursion (%)	106 ± 4	100 ± 12	0.70‡	11	0.20
End point excursion (%)	93 ± 12	89 ± 16	0.31	16	0.58
Velocity ($°\cdot s^{-1}$)	8.7 ± 4.2	8.2 ± 3.6	0.14	4.6	0.80
Dominant side					
Maximum excursion (%)	97 ± 6	94 ± 9	0.38	8.9	0.50
End point excursion (%)	79 ± 15	79 ± 15	0.02	17	0.97
Velocity ($°\cdot s^{-1}$)	7.9 ± 4.1	8.1 ± 2.9	0.05	4.1	0.93
Diagonal (backward and dominant side)					
Maximum excursion (%)	95 ± 12	101 ± 7	0.67‡	11	0.22
End point excursion (%)	83 ± 20	92 ± 13	0.53‡	19	0.34
Velocity ($°\cdot s^{-1}$)	5.0 ± 1.8	8.1 ± 1.9	1.30§	2.2	0.01‖
Backward					
Maximum excursion (%)	91 ± 10	77 ± 14	1.00§	14.3	0.06
End point excursion (%)	69 ± 19	64 ± 22	0.28	24	0.62
Velocity ($°\cdot s^{-1}$)	4.7 ± 2.3	4.5 ± 2.1	0.11	2.6	0.84
Diagonal (backward and nondominant side)					
Maximum excursion (%)	94 ± 9	96 ± 7	0.18	10	0.75
End point excursion (%)	86 ± 15	90 ± 11	0.29	15	0.61
Velocity ($°\cdot s^{-1}$)	7.3 ± 3.0	6.9 ± 2.1	0.16	3.0	0.77
Nondominant side					
Maximum excursion (%)	96 ± 5	96 ± 8	0.02	8	0.97
End point excursion (%)	86 ± 8	74 ± 4	1.40§	7	0.01‖
Velocity ($°\cdot s^{-1}$)	9.2 ± 4.3	7.5 ± 2.3	0.48	4	0.39
Diagonal (forward and nondominant side)					
Maximum excursion (%)	106 ± 9	103 ± 6	0.36	9	0.53
End point excursion (%)	96 ± 13	86 ± 17	0.64‡	18	0.25
Velocity ($°\cdot s^{-1}$)	9.3 ± 3.9	6.4 ± 2.5	0.82§	3.8	0.13

*CL = 95% confidence limit defines the range representing the uncertainty in the true value of the (unknown) population mean; mIAT = modified Illinois agility test; 3RM squat = 3 repetition maximum back squat.
†d_a indicates effect size.
‡Moderate between-group condition difference in the effect size (value = 0.50–0.79).
§Large between-group condition difference in the effect size (value ≥0.80).
‖A significant between-group difference, $p \leq 0.05$.

Table 2. Statistical results for the joint angles and peak net internal joint moments displaced during a reactive change-of-direction task for participants with HIGH and LOW trunk control.*†‡

	IC			F_{V1}			F_{WA}			F_{V2}			TO			Joint moment (N·m·kg^{-1})			
Joint angles (°)	d_a	CL	p	d_a	CL	p	d_a	CL	p	d_a	CL	p	d_a	CL	p		d_a	CL	p
Ankle dorsi-plantar flexion	0.01	5.9	0.98	0.18	11.6	0.75	0.63§	9.9	0.25	0.33	8.6	0.56†	0.99‖	7.8	0.06†	Ankle plantar flexion	0.22	1.09	0.70
Forefoot adduction-abduction	1.04‖	6.5	0.05¶	0.68§	9.1	0.22	0.91‖	6.3	0.09	0.91‖	6.8	0.09	0.59§	6.7	0.29	Forefoot adduction	0.59§	0.91	0.29
Ankle eversion-inversion	0.08	11.1	0.89	0.26	17.2	0.65	0.38	13.7	0.50	0.06	13.4	0.92	0.21	13.3	0.72	Forefoot abduction	0.12	0.98	0.83
Knee flexion-extension	1.75‖	5.3	0.00¶	0.40	4.5	0.45	0.60§	4.3	0.28	0.12	6.6	0.84	1.14‖	17.8	0.03¶	Ankle inversion	0.09	0.99	0.87
Knee adduction-abduction	0.29	5.1	0.52	0.20	6.9	0.75	0.30	6.0	0.60	0.26	6.7	0.65	0.15	3.5	0.79	Ankle eversion	0.12	0.98	0.84
Knee internal rotation	0.44	8.2	0.37	0.12	15.0	0.84	0.66§	9.0	0.23	0.17	8.2	0.77	0.56§	16.9	0.31	Knee extension	0.29	1.33	0.61
Hip flexion-extension	0.07	7.5	0.91	0.05	8.4	0.93	0.00	9.9	1.00	0.17	11.6	0.76	0.64§	10.9	0.25	Knee adduction	0.33	1.13	0.56
Hip adduction-abduction	0.21	4.8	0.72	0.22	5.8	0.70	0.17	7.0	0.77	0.49	6.8	0.38	0.45	5.9	0.43	Knee abduction	0.14	1.20	0.80
Hip internal-external rotation	0.47	12.2	0.40	0.02	12.5	0.97	0.35	9.8	0.54	0.39	8.7	0.49	0.10	10.1	0.86	Knee internal rotation	0.36	0.99	0.53
L5-S1 flexion-external	0.54§	11.6	0.33	0.30	12.0	0.60	0.13	11.6	0.82	0.12	11.7	0.83	0.11	12.2	0.85	Knee external rotation	0.47	0.96	0.40
L5-S1 left-right lateral flexion	0.14	4.0	0.80	0.16	3.6	0.77	0.35	4.7	0.54	0.14	5.0	0.81	0.02	4.3	0.97	Hip flexion	0.14	1.14	0.81
L5-S1 right-left rotation	0.39	5.3	0.49	0.30	4.9	0.60	0.30	3.7	0.60	0.13	2.9	0.81	0.05	4.9	0.93	Hip extension	0.05	1.35	0.93
T12-L1 flexion-extension	0.27	6.6	0.63	0.41	7.0	0.47	0.40	8.0	0.48	0.11	8.9	0.85	0.11	10.8	0.84	Hip adduction	0.12	1.34	0.84
T12-L1 left-right lateral flexion	0.64§	11.1	0.24	0.58§	10.9	0.30	0.32	12.0	0.57	0.19	10.8	0.74	0.94‖	5.5	0.08	Hip abduction	0.36	1.20	0.53
T12-L1 right-left rotation	0.39§	9.7	0.49	0.51§	8.6	0.37	0.65§	5.1	0.24	0.36	4.4	0.53	0.35	5.0	0.53	Hip internal rotation	0.49	0.96	0.38
Trunk-pelvis flexion-extension	0.78§	11.6	0.15	0.77§	10.8	0.16	0.54§	11.3	0.33	0.15	11.0	0.80†	0.24	9.2	0.67	Hip external rotation	0.82‖	0.92	0.13
Trunk-pelvis left-right lateral flexion	0.03	6.9	0.96	0.15	5.7	0.79	1.09‖	4.3	0.03¶	1.31‖	3.0	0.01¶	0.51§	5.2	0.36	L5-S1 flexion	0.41	2.09	0.47

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Trunk-pelvis right-left rotation	1.42‖	6.6	0.00¶	1.50‖	5.5	0.00¶	0.98‖	5.7	0.06	0.33	5.5	0.56	1.04‖	4.6	0.05¶	L5-S1 extension	0.29	0.87	0.61
															L5-S1 left lateral flexion	0.36	1.27	0.53
															L5-S1 right lateral flexion	0.65§	1.30	0.24
															L5-S1 right rotation	0.19	0.97	0.74
															L5-S1 left rotation	0.30	1.48	0.60
															T12-L1 flexion	0.34	1.16	0.54
															T12-L1 extension	0.33	0.87	0.56
															T12-L1 left lateral flexion	0.96‖	1.42	0.07
															T12-L1 right lateral flexion	0.06	1.27	0.91
															T12-L1 right rotation	0.44	1.11	0.43
															T12-L1 left rotation	0.12	1.79	0.83

*IC = initial foot-ground contact; F_{V1} = first peak vertical GRF; WA = weight acceptance; F_{WA} = first local minimum of the vertical GRF after F_V; F_{V2} = second peak vertical GRF; TO = toe-off; CL = 95% confidence limit defines the range representing the uncertainty in the true value of the (unknown) population mean; GRF = ground reaction force.

†For the above rotations, ankle dorsiflexion, forefoot adduction, ankle eversion, knee flexion, knee adduction, knee internal rotation, hip flexion, hip adduction, hip internal rotation, L5-S1 flexion, L5-S1 left lateral flexion, L5-S1 right rotation, T12-L1 flexion, T12-L1 left lateral flexion, and T12-L1 right rotation are positive.

‡d_a indicates effect size.

§Moderate between-group condition difference in the effect size (value = 0.50–0.79).

‖Large between-group condition difference in the effect size (value ≥0.80).

¶A significant between-group condition difference, $p \leq 0.05$.

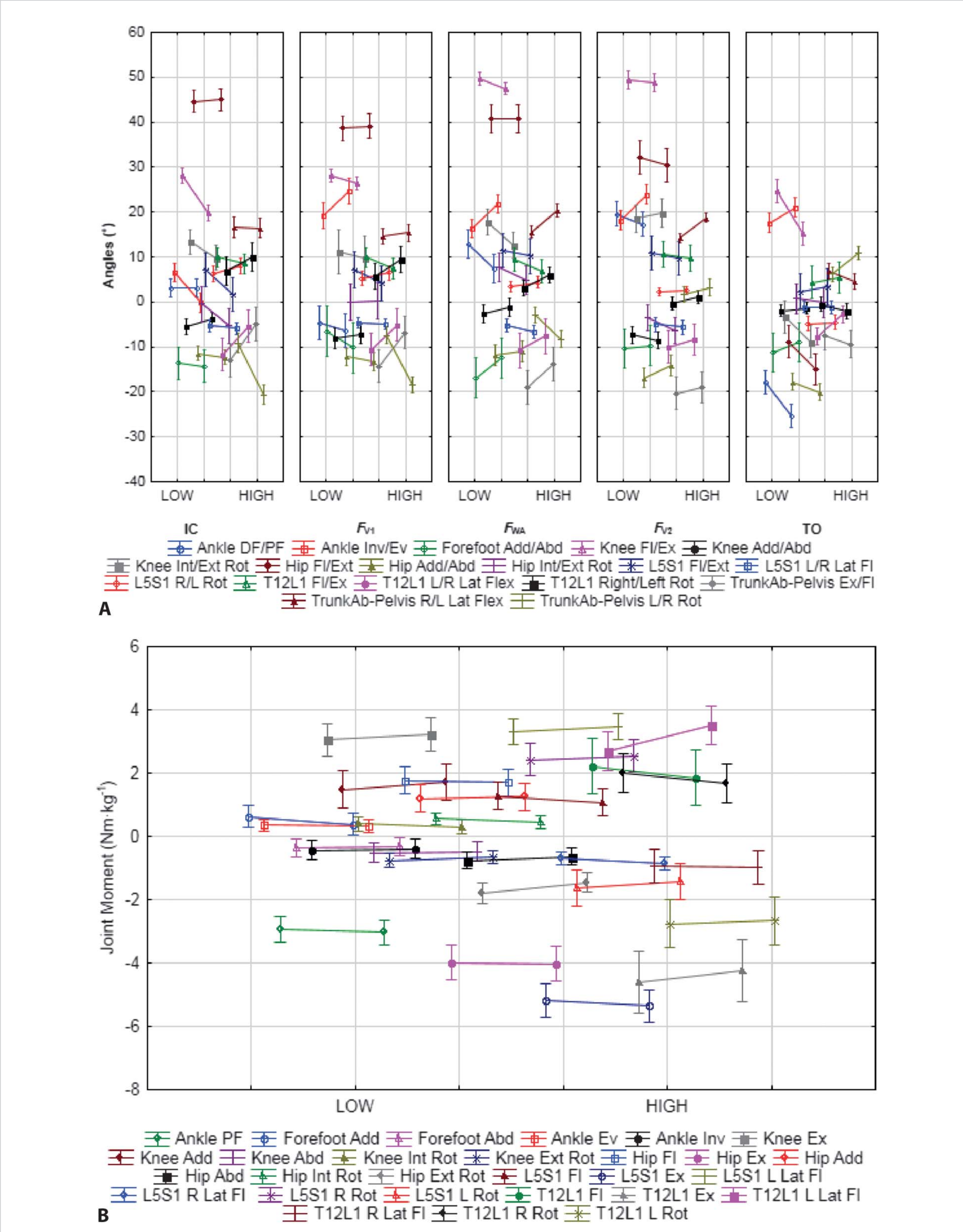

Figure 3. Mean ± *SD* of the (A) joint angles (°) and (B) peak net internal joint moments (N·m·kg^{-1}) displaced during a reactive change-of-direction task for participants with HIGH and LOW trunk control.

slower during the diagonal forward and nondominant side direction.

Kinematics

No significant differences were observed for any hip, L5-S1 joint, or T12-L1 joint angle variables nor location of the foot segment relative to the body center of mass (Table 2 and Figure 3). However, the HIGH group displayed significantly smaller forefoot adduction angle at IC and knee flexion angles at IC and TO when compared with the LOW group. The HIGH group used a significantly greater total (HIGH = 68.3 ± 8.0°, LOW = 44.1 ± 5.4°; $p < 0.001$, $d = 1.71$, 95% confidence interval [CI] = 8), flexion-extension (HIGH = 17.6 ± 4.5°, LOW = 12.4 ± 2.8°; $p < 0.02$, $d = 1.15$, 95% CI, 4.4), and rotation (HIGH = 33.1 ± 5.1°, LOW = 18.8 ± 3.9°; $p < 0.001$, $d = 1.66$, 95% CI, 5.3) trunk relative to pelvis ROM during the R-COD compared with the LOW group (lateral flexion: HIGH = 17.7 ± 4.2°, LOW = 12.8 ± 5.4°; $p = 0.08$, $d = 0.93$, 95% CI, 5.6). Trunk relative to pelvis joint angles were significantly larger for the HIGH group for right trunk rotation at the time of IC, at the time of F_{V1}, and at the time of TO and trunk lateral flexion to the right at times of F_{WA} and F_{V2} compared with the LOW group.

Kinetics

Significant differences were observed in neither GRF (Table 3 and Figure 4) nor peak joint moment variables between the HIGH and LOW groups throughout the R-COD (Table 2). During the WA phase, the HIGH group displayed significantly greater peak anterior and change in anteroposterior angular momentum compared with the LOW group. Whereas for the mediolateral angular momentum, the HIGH group displayed a more neutral value at IC and greater peak angular momentum away from the direction of travel during the WA phase and less away from the direction of travel at TO.

TABLE 3. Statistical results for the (A) peak GRF, (B) timing of peak GRF, (C) GRF impulse, and (D) FV loading rate, (E) ratio of peak GRF, (F) angular momentum, and (G) location of the foot segment relative to the body center of mass during a reactive change-of-direction task for participants with HIGH and LOW trunk control.*†

Variable	d_a	CL	p	Variable	d_a	CL	p
Force				Location of COG foot segment relative to model COG (cm)			
F_{V1} (BW)	0.11	0.8	0.83	Mediolateral displacement	0.11	5.7	0.85
F_{WA} (BW)	0.08	0.3	0.87	Lateral displacement at IC	0.46	7.0	0.41
F_{V2} (BW)	0.77	0.1	0.08	Lateral displacement at TO	0.32	8.4	0.58
F_{POST} (BW)	0.23	0.5	0.69	Anteroposterior	0.20	11.1	0.73
F_{ANT} (BW)	0.26	0.1	0.76	Posterior location at IC	0.27	9.8	0.64
LR F_{V1} ($BW \cdot s^{-1}$)	0.41	52	0.45	Anterior location at TO	0.77‡	5.88	0.16
IC-F_{V1} (ms)	0.41	8	0.43	Angular momentum			
IC-F_{WA} (ms)	3.18§	73	0.34	Anteroposterior at IC	0.31	1.01	0.58
IC-F_{V2} (ms)	2.34§	78	0.31	Peak anteroposterior WA	1.17§	1.24	0.02‖
IC-TO (ms)	0.27	39	0.59	Change anteroposterior WA	1.23§	1.01	0.01‖
IC-F_{POST} (ms)	1.24§	6	0.11	Anteroposterior at TO	0.05	1.20	0.93
IC-F_{ANT} (ms)	0.37	33	0.37	Peak anteroposterior PP	0.39	1.35	0.49
F_V impulse ($BW \cdot s$)	0.63	0.04	0.34	Change anteroposterior PP	0.60‡	1.13	0.28
F_{Post} impulse ($BW \cdot s$)	0.86§	0.02	0.13	Mediolateral at IC	1.27§	0.90	0.01‖
F_{Ant} impulse ($BW \cdot s$)	0.39	0.01	0.39	Peak mediolateral WA	1.27§	1.10	0.01‖
F_{AP} net impulse ($BW \cdot s$)	0.80§	0.03	0.13	Change mediolateral WA	0.21	1.41	0.71
Ratio F_{POST} to F_{V1} (%)	0.48	10	0.39	Mediolateral at TO	1.09§	0.99	0.03‖
Ratio F_{ANT} to F_{V2} (%)	0.45	3	0.42	Peak mediolateral PP	0.30	1.02	0.60
				Change mediolateral PP	1.00§	1.03	0.06

*GRF = ground reaction force; CL = 95% confidence limit defines the range representing the uncertainty in the true value of the (unknown) population mean; F_{V1} = first peak vertical GRF after initial foot-ground contact; WA = weight acceptance; F_{WA} = first local minimum of vertical GRF after IC; IC = initial foot-ground contact; F_{V2} = second peak vertical GRF after initial foot-ground contact; F_{POST} = peak posterior GRFs; F_{ANT} = peak anterior GRF; LR F_{V1} = loading rate of the F_{V1}; IC-F_{V1} = time interval between IC and the time of the F_{V1}; IC-F_{WA} = time interval between IC and the time of the F_{WA}; IC-F_{V2} = time interval between IC and the time of the F_{V2}; IC-TO = time interval between IC and the time of the toe-off; IC-F_{POST} = time interval between IC and the time of the F_{POST}; IC-F_{ANT} = time interval between IC and the time of the F_{ANT}; PP = propulsion phase; F_V impulse = vertical GRF impulse; F_P impulse = posterior GRF impulse; F_A impulse = anterior GRF impulse; F_{AP} net impulse = anterior-posterior net force impulse; COG = center of gravity.

†d_a indicates effect size.

‡Indicates moderate between-group difference in the effect size for a value between 0.50 and 0.79.

§Indicates large between-group difference in the effect size for a value greater than 0.80.

‖Indicates a significant between-group condition difference, $p \leq 0.05$.

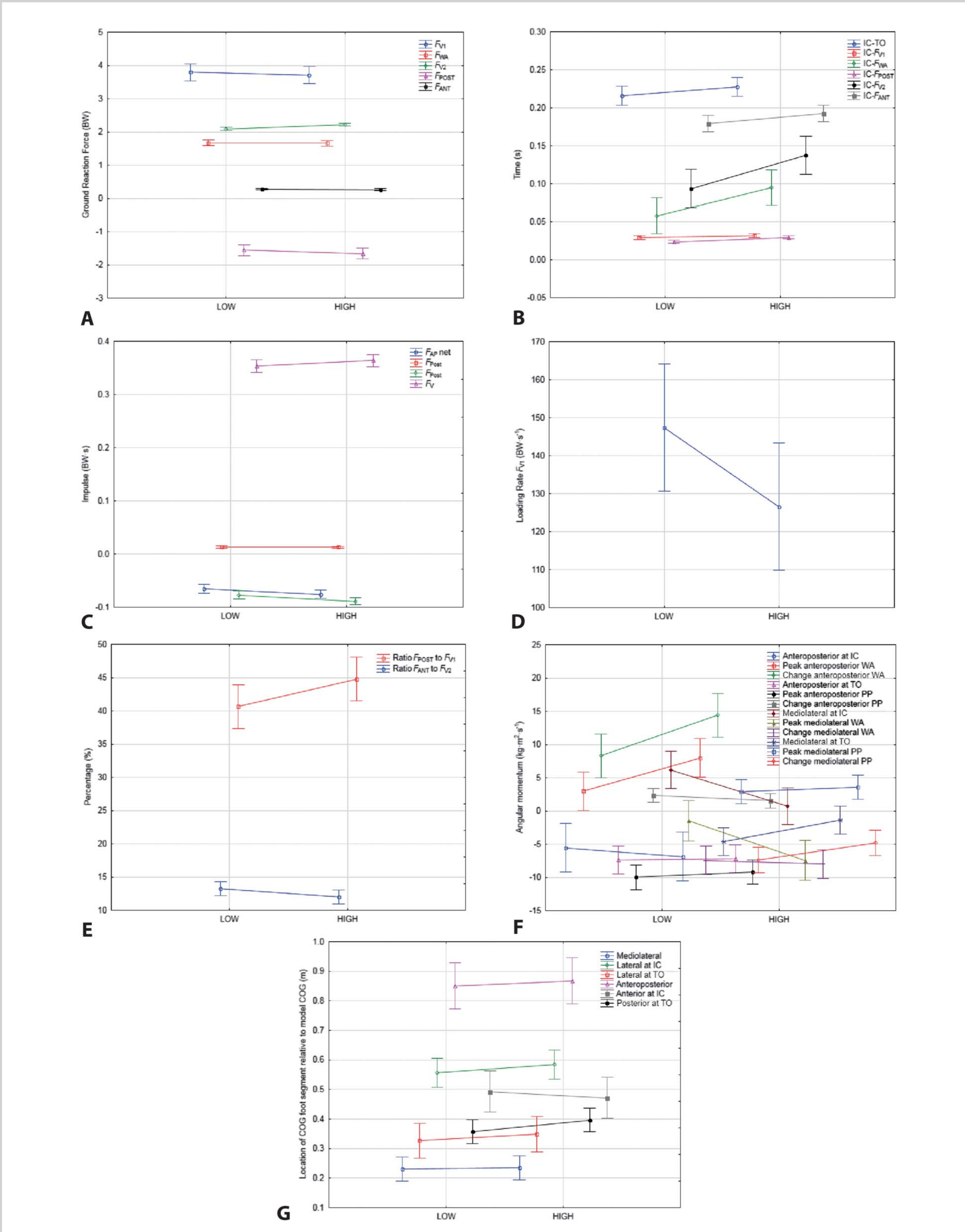

Figure 4. Mean ± *SD* of the (A) peak ground reaction force (GRF) (relative BW), (B) timing of peak GRF (second), (C) GRF impulse (BW per second), and (D) FV loading rate (BW·per second), (E) ratio of peak GRF (%), (F) angular momentum (kilogram × square meter·per second), and (G) location of the foot segment relative to the body center of mass (m) during a reactive change-of-direction task for participants with HIGH and LOW trunk control.

Discussion

Previous literature suggests that the trunk plays an integral part in athletic performance by forming a critical link between the upper and lower limbs, enabling optimal dissipation of force between body segments as a result of increased trunk control (6). The current study hypothesis was not supported as participants who used a higher trunk control, LOW group (low trunk ROM) during an R-COD displayed poorer performance during field-based athletic performance tests. The LOW group (stable trunk) demonstrated this by significantly slower mIAT time and lower CMJ height when compared with the HIGH group (unstable trunk). Between-group differences were observed in neither 20-m sprint time nor absolute or relative 3RM squat, which highlights the ambiguity of the between-study difference in the relationship of these field-based assessments with agility (9,21,42). The lower absolute and relative 3RM squat values in this study compared with higher skilled team sport athletes at a professional (9) or semiprofessional level (41) may have confounded the relationship between 3RM and athletic performance. Nevertheless, it is recommended that to improve athletic performance, ground-based lifts (squats, deadlift, and Olympic lifts) should be employed to train the core to improve athletic performance (5) because of the higher core muscular activation than core stability ball exercises (33). Nevertheless, the weak relationship 3RM squat between groups suggests that the performance of the squat, a ground-based lift, did not affect athletic performance in this study. Although the core is recommended to be trained for athletic conditioning via performing these "big 3" exercises (cleans, deadlifts, and squats), it is possible that the transfer-of-training effect may be insufficient to elicit the use of the core to control the trunk in R-COD.

Despite significant between-group differences in the field-based assessments of performance, there were no significant between-group differences observed for the hip, L5-S1, or T12-L1 joint angles, GRF variables, or any peak net internal ankle, knee, hip, L5-S1, or T12-L1 joint moments throughout the R-COD. It is acknowledged that this lack of statistically significant between-group differences in the plant-and-cut maneuver may be because of the limited sample sizes used within this study. Nevertheless, despite the lack of statistically significant data, the magnitude of effect sizes indicates the strength of the relationship between groups (4) and avoids the shortcomings of research based in null hypothesis significance testing (16). Consequently, moderate or large effect sizes during an R-COD may assist in explaining why the HIGH group displayed superior performance in comparison with the LOW group in field-based performance measures. Therefore, because of the exploratory nature of this study, moderate and large effect sizes will also be discussed to explore and assist explaining the significant between-group differences between trunk control and performance during an R-COD.

The HIGH group displayed significant greater flexion-extension and rotation ROM compared with the LOW group throughout the R-COD. Players with lower trunk control achieved this higher trunk ROM by positioning their trunk more upright and rotated away from the direction of travel at IC, then they continued to laterally flex their trunk away from the direction of travel more as they flexed their trunk, and then rotated their trunk more toward the direction of travel as they became more upright and decreased their lateral flexion compared with the LOW group. This technique may enable these HIGH participants better athletic performance in the field-based test of performance by enabling the athletes to create greater peak anterior momentum and, change in anteroposterior angular momentum during the WA phase and a neutral mediolateral angular momentum at IC, to enable the HIGH participant to effect a change of direction more rapidly toward the direction of travel.

A critical component of agility and team sport performance is the ability to develop higher acceleration and achieve maximal speed more quickly (24). This can be achieved during straight-line sprinting by athletes who are able to position the center of mass more anteriorly relative to the ground contact point to create a higher ratio of horizontal to vertical GRF (17). In this study, the players with lower trunk control (high trunk ROM) and superior agility performance displayed a moderately greater anterior position of the foot relative to the body center of mass at TO, but this did not generate a higher ratio of horizontal relative to vertical GRF. A change in posture is likely to change the orientation of the center of mass relative to the base of support (22). It is postulated that the HIGH group's greater flexion of the trunk segment relative to the pelvis segment during the WA phase led to the greater anterior position of the foot relative to the body center of mass at TO and the significant greater peak anterior and change in angular momentum during the WA phase compared with the LOW group. Together these may have contributed to their superior field-based assessment performance. Superior agility performance has been associated with greater rotation toward the direction of travel (25), which supports the findings of this study of greater trunk rotation ROM during the R-COD. However, previous research has not observed an association with the lateral trunk flexion during an agility task with superior agility performance (35), contrast to the findings of this study. That is, the HIGH group demonstrated significantly greater lateral flexion angles of the trunk segment relative to the pelvis segment at times of the F_{WA} and F_{V2} away from the new direction of travel in comparison with the LOW group. This greater lateral trunk flexion lead to a more greater peak mediolateral angular momentum away from the direction of travel during the WA phase but could not be explained by between-group differences in lateral foot placement relative to the center of mass at IC or TO. In addition, a significantly more neutral forefoot adduction-abduction position at IC displayed by the HIGH group enables the athlete to respond to the environmental demands of an unanticipated direction of the COD and contributed to the neutral mediolateral angular momentum at IC and TO. Together these might have contributed to the faster mIAT time of the HIGH group compared with the LOW group.

Despite significant between-group differences in relative trunk segment to pelvis segment angles throughout the stance phase, there were no significant differences in L5-S1 or T12-L1 joint angles throughout the contact period of the R-COD. Facet joints of the lumbar vertebrae allow less axial rotation compared with the thoracic vertebrae (6), which may in part explain why no significant differences or substantial effect sizes for L5-S1 joint angles between groups were observed; however, large effect sizes for T12-L1 joint angle between-group differences at T12-L1 joint throughout the contact period of the R-COD were observed. It is these between-group differences in T12-L1 joint angles that most likely contributed to significant trunk relative to pelvis angles throughout the contact period of the R-COD.

Change-of-direction techniques either involving the torso less (37) or greater trunk flexion (10), laterally flexing (11,20), or rotating and laterally flexing (11) away from the direction change place the athlete at greater risk of anterior cruciate ligament rupture via increasing knee joint moments (11,20). Nevertheless, despite the HIGH group using greater trunk flexion, lateral trunk flexion, and rotation during the R-COD compared with the LOW group, there were no significant between-group differences or moderate or large effect sizes in peak internal knee adduction or internal or external rotation joint moments. Furthermore, a lack of significant between-group differences in any of the peak joint moments during the contact phase was noted. It should be noted that although there was a moderate (L5-S1 right lateral flexion) and large (hip external rotation and T12-L1 left lateral flexion) effect size between-group difference in joint moments, the small change in mean and high 95% CI suggest that this result is unclear and may not be clinically relevant.

A shorter (12,35) or no difference in foot-ground contact time duration and higher vertical F_{V1} and F_{V3}, posterior GRF, and posterior and anterior GRF impulses (42) has been linked with superior agility performance. Although there were no significant differences evident for any GRF variables during the R-COD, the HIGH group demonstrated substantially moderate to large effect sizes for longer foot-ground time contact duration and higher vertical and large posterior impulses compared with the LOW group. This may explain the superior field-based performances of the HIGH group. The lack of agreement with previous research between shorter contact periods and superior agility performance may be attributable to the previous studies not controlling the approach speed (12) or the effect of task dependence. Nevertheless, the results of this study were in agreement with the longer contact time with superior sprinting performance (22), which may have contributed to the longer GRF application and in turn higher vertical and posterior GRF impulses observed in this study.

Force dissipation strategy can be used during landing tasks by employing a larger range of knee flexion ROM and foot-ground contact time duration to decrease the magnitude of the peak GRFs and loading rates and in turn potentially lowering the risk of lower-limb injury (43). This strategy was observed in the HIGH group who displayed significantly less knee flexion at IC and TO, indicating that they used a relatively larger knee joint flexion ROM in comparison with the LOW group. Not only did this force dissipation strategy used by the HIGH group potentially lower the risk of a lower-limb injury but may also have contributed to performance enhancement.

Results of this study support the argument that the trunk mechanics exerts influence on athletic performance; however, the exact mechanism for potentiation of performance in R-COD and team sport performance is less clear, and further investigation is urgently warranted. The core is unlikely to function to optimize performance by limiting trunk motion in all 3 planes during athletic movement. Instead, it enables motion within an optimal range to capitalize on the efficient utilization of the stretch-shortening cycle and manage postural changes and the orientation of the center of mass relative to the base of support. This enables optimal application of force along the desired vector, thereby maximizing the efficiency of application of propulsive force. Furthermore, limiting trunk motion during walking has been observed in individuals with lower-back pain who adopt a protective strategy by using a guarding or splinting behavior through the activation of superficial trunk muscles that increase trunk stiffness (2). From the results of this study, it is speculated that the LOW group may have activated the superficial core musculature and adopted a splinting strategy during the execution of the R-COD as a compensatory mechanism for possessing poor trunk control. Whereas the HIGH group may have used a more optimal activation of the deep core musculature to enable greater trunk segment relative to pelvis segment ROM to enhance performance. The conditioning principle of specificity suggests that training is most efficient when training replicates performance conditions and criteria and core training in athletes should employ ground-based lifts (squats, deadlift, and Olympic lifts) (5) because of the higher core muscular activation than core stability ball exercises (33). Therefore, based on the results of the present study and the clinical link of splinting behavior with injury, exercises that require increased trunk rigidity and use small core ROM to increase trunk control may not optimally prepare athletes for competition. This raises questions regarding current strength and conditioning practices for minimizing trunk motion during agility to optimize agility or employing ground-based lifts to train the core and urgently warrants further research. To provide further insight into the relationship between core control and performance, researchers should repeat the current study's experimental protocol with a larger sample size with different skill level, gender, or age, with the additional inclusion of body composition data. The cross-sectional design of this study is a limitation as it is unknown if the difference in trunk control during the R-COD between groups was an effect of training history or inherent. As previous research has shown that team sport athletes can retrain their trunk mechanics during a COD task (10), researchers should investigate if trunk control can also be retrained during an R-COD via technique modification or core retraining employing the big 3 exercises and if retraining trunk control during an R-COD alters athletic performance and injury risk. This future research will enable researchers to ascertain if the trunk control is inherent or can be altered by training and the optimal training method.

Practical Applications

The results of this study do not support current recommendation that athletes require minimal trunk ROM during an agility task to optimize athletic performance. Decreased trunk control (high trunk ROM) during an R-COD may function facilitating superior athletic performance via enabling the storage, transmission, and control of forces across the system while manipulating body posture to maintain spinal stability. This may enable the athlete to orientate the center of mass relative to the base of support to optimize the ratio of horizontal to vertical force vectors and acceleration. Consequently, current strength and conditioning practices using increased trunk control during conditioning drills may not optimally prepare athletes for the demands of competition. Although this study suggesting that trunk control is a vital component of performance, future research should investigate whether this trunk control is inherent or an effect of training history, and whether the current optimal athletic performance recommendation of decreased trunk motion during R-COD are supported.

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