Kinematic Factors Affecting Fast and Slow Straight and Change-of-Direction Acceleration Times

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Abstract

Hewit, JK, Cronin, JB, and Hume, PA. Kinematic factors affecting fast and slow straight and change-of-direction acceleration times. *J Strength Cond Res* 27(1): 69–75, 2013—In many sports, players are often required to accelerate immediately after rapid changes of direction (CODs) before performing a subsequent COD movement. Therefore, court-based players will often not attain their maximum velocity before having to decelerate and change direction. The purpose of this study was to determine what kinematic factors affected fast and slow straight acceleration (SA) and change-of-direction acceleration (CODA) times. National under-21 netball players performed 3 trials each of a 2.5-m SA and a CODA involving a 180° COD followed immediately by a 2.5-m sprint. Players were grouped into either a faster or slower category based on performance times (2.5-m time). Significantly higher average step frequency (4%, $p = 0.03$) was observed for the faster group when compared with the slower group in the CODA task. For the SA task, faster times were associated with significantly smaller average step lengths (SLs; 7%, $p = 0.03$), greater torso angles (i.e., greater forward lean; 30–37%, $p < 0.001$), and smaller hip angle (less knee lift) in the first step (21–22%, $p = 0.00$). The SA task was associated with significantly longer average SLs (21–23%, $p = 0.00$) and significantly longer SL across all 3 steps as compared with the CODA task (17–27%, $p < 0.001$) A significantly increased forward lean was associated with the first step of the SA task (34%, $p < 0.001$) and significantly higher knee lift for the first and second steps of the SA task (11–22%, $p = 0.00$ and 0.04, respectively). These kinematic differences can be used for training purposes for both coaches and strength and conditioning practitioners.

Key Words step length, step frequency, knee lift, sprinting, technique

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Introduction

The ability to travel from one point to another as quickly as possible is a desirable quality and prerequisite to success in many activities and sports. As illustrated in Figure 1, straight sprinting speed is one of the main qualities that contribute to the effectiveness of a change-of-direction (COD) performance. For many sports, numerous bouts of rapid increases and decreases in velocity (i.e., acceleration and deceleration) (12,20) are required as a result of the defined area of play and to pursue or evade other players or objects. As such, players will be required to accelerate from a static start (i.e., straight acceleration [SA]) and immediately after a rapid directional change (i.e., change-of-direction acceleration [CODA]). Furthermore, the sprints in many sports will take place over very short distances (i.e., <10 m) (7).

Although there is a great deal of literature that investigates the kinematics and kinetics of speed (2,3,18), these analyses are performed using straight-line movements over distances (50–200 m) that are for the most part unrelated to many sports, particularly court-based sports (5,6,9,10,13–15,26). That is, in many sports, players are often required to accelerate between consecutive CODs, and as a result, the kinematics of importance is over the first few steps. Therefore, a court-based player will most likely not attain anywhere near his or her maximum velocity before having to decelerate and change direction again. As a result, a player who is able to excel in straight-line sprints may not have the same success accelerating out of a rapid COD and vice versa. This may be especially the case for larger players who have greater inertia (resistance to motion) to overcome and, once moving, have a great deal of momentum (mass × velocity) to control.

Research investigating the relationship between straight-line acceleration ability and COD ability (i.e., performance times) has shown little correlation between the two (1,19,21,24). This is to be expected because the technical characteristics required for each movement task (e.g., step length [SL], step frequency [SF], body positioning) are likely to differ greatly. To the knowledge of the authors of the current study, no research has been published comparing the individual technical characteristics or kinematics between

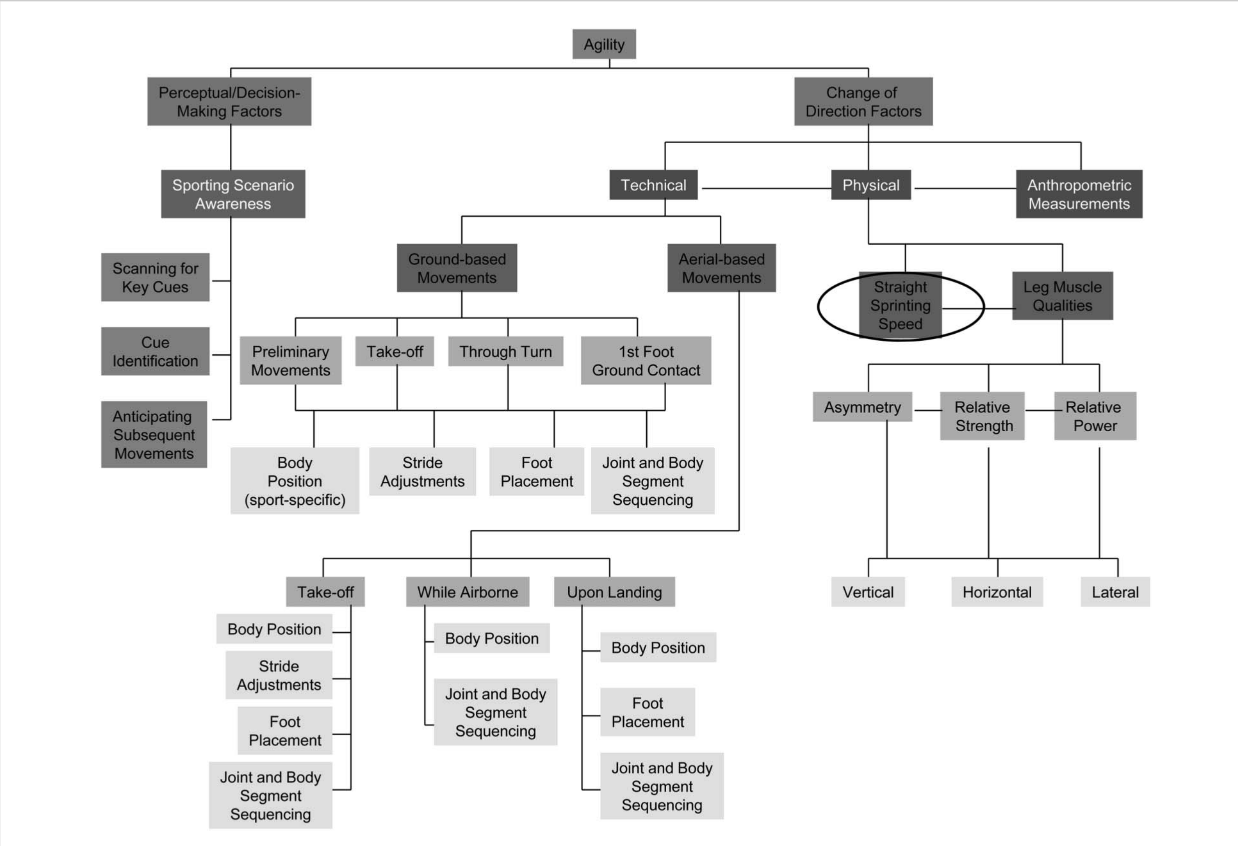

Figure 1. Key contributing components of agility, with the straight sprinting speed subcomponent circled.

sports or tasks. For example, body positioning when accelerating is likely to vary markedly between a field hockey player with the ball on the ground (e.g., increased torso lean and hip and knee flexion) and a netball or basketball player where the ball is elevated off the ground (e.g., more erect torso with decreased hip and knee extension). As such, when training CODA in athletes, appropriate "cuing" (e.g., decrease the length of steps, keep the torso up) from coaches is thought to be necessary to optimize performance, and therefore, research in this area is needed.

Although COD movements are often performed in succession to one another in court-based sports, it is hypothesized that body positioning and stride characteristics when accelerating between COD movements differ greatly when compared with SA with no additional alterations to direction or velocity. In their research investigating top running speeds of men and women, Weyand et al. (23) found that faster performances were a result of increased ground reaction forces and more rapid repositioning of limbs. The longer the free leg is in the air, the longer the duration before a ground reaction force is applied to change direction. Therefore, an increased hip angle at contralateral takeoff combined with an abbreviated SL is hypothesized to be associated with better COD performance. An increased forward lean typically associated with SA performances would result in an increased takeoff distance as the center of mass is brought forward of the takeoff leg, and would contribute to a longer SL and result in a longer interval between propulsive foot strikes (4,11,17,18). Additionally, a decreased forward lean (smaller torso angle) would position the center of mass closer to the base of support, increasing stability when completing rapid CODs. Therefore, it was hypothesized that a decreased forward lean would be present in the better CODA task performances. Given these hypotheses, the primary purpose of this article was to compare the stride characteristics and body positioning adopted by faster and slower court-based team players during the first 3 strides when accelerating in an SA with those of the acceleration after a rapid 180° ground-based COD movement. The secondary purpose was to identify key technical features associated with CODA to assist coaches and strength and conditioning practitioners in their understanding of how to condition and "cue" for more effective CODA ability.

Methods

Experimental Approach to the Problem

This study analyzed the technical differences in 2 acceleration tasks: (a) SA, a 5-m straight sprint from a static start with a 2.5-m split time; and (b) CODA, a rapid 180° ground-based COD from a static start followed immediately by a 2.5-m straight sprint (commonly performed throughout various court-based sports such as netball and basketball). To elicit a "natural" acceleration performance from each player, specific instructions about the tasks were kept to a minimum and each subject was instructed to "perform the tasks as fast as you can, as if you were in a game." High-speed video was used to quantify torso and hip angles, and SL through the first 3 steps of the acceleration phase for each task. Players were divided into 2 groups based on performance times and the kinematic variables of interest statistically compared for intergroup differences.

Subjects

A total of 22 players from the national under-21 training squad participated in this study. Testing took place in the morning during a preseason training camp. At the time of testing, all participants were free of injury. Before completing the warm-up, the age (19.3 ± 1.1 years), height (1.79 ± 0.06 m), and body mass (77.1 ± 1.0 kg) were recorded for each player. Players had no specific sprint or COD speed training before testing other than as outlined in the Testing Procedures subsection. The human research ethics committee of Auckland University of Technology approved all procedures before commencing the study. Before participation, an informed written consent was obtained from each athlete.

Equipment

Three sets of dual-beam timing lights (60 m high; Swift Performance Equipment, Wacol, Queensland, Australia) and a 300-Hz high-speed video camera (Casio EX-F1; Casio Computer Co., Ltd., Tokyo, Japan) were used for data collection. The players' start mark was designated by a 1-m-long piece of floor tape. The timing lights were placed 2 m apart at 0.3 m from the start mark, 2.5 m beyond the start mark, and 5.0 m beyond the start mark. The high-speed camera was placed 5.5 m away from the start mark, perpendicular to the sprinting direction, and calibrated using a calibration board of known measurements facing the camera at the start mark. Video was analyzed using a combination of Quick Time 7 Pro (Apple, Inc., Cupertino, CA, USA) and SiliconCoach Pro software (SiliconCoach, Dunedin, New Zealand). Sprint and split times were recorded from the timing gates after each trial.

Testing Procedures

Testing was performed within 1 session on an indoor netball court with sprung wooden floors. After a standardized warm-up, markers were placed at the following locations for analysis: acromion process, greater trochanter, lateral epicondyle, and lateral malleolus. Players were allowed up to 3 practice trials of each of the 2 movement tasks before data collection. For the SA task, players began in a parallel stance with both toes at the start mark. When ready, the player sprinted with maximal effort through all 3 timing lights. Once all players had performed 3 trials of the SA, 3 trials of the

Figure 2. Description of torso angle as measured from the vertical.

Figure 3. Description of hip angle as measured from the horizontal.

Table 1. Squad rankings for mean (*SD*) of straight acceleration (SA) and change-of-direction acceleration (CODA) 2.5-m times for faster and slower groups.

	Player	SA 2.5 m	Player	CODA 2.5 m
Faster	1	0.72 (0.02)	2	0.59 (0.06)
	2	0.74 (0.02)	1	0.61 (0.02)
	17	0.76 (0.02)	18	0.61 (0.04)
	11	0.76 (0.03)	11	0.61 (0.05)
	12	0.77 (0.06)	16	0.61 (0.04)
	4	0.78 (0.01)	4	0.62 (0.04)
	3	0.78 (0.01)	12	0.62 (0.04)
	6	0.78 (0.03)	19	0.62 (0.02)
	7	0.78 (0.01)	9	0.64 (0.02)
	22	0.78 (0.01)	3	0.64 (0.02)
	10	0.79 (0.04)	5	0.64 (0.04)
	Group mean (*SD*)	0.77 (0.02)	Group mean (*SD*)	0.62 (0.01)
Slower	16	0.79 (0.02)	10	0.64 (0.04)
	19	0.79 (0.02)	8	0.65 (0.01)
	9	0.81 (0.03)	13	0.65 (0.01)
	14	0.81 (0.02)	7	0.66 (0.01)
	20	0.82 (0.01)	6	0.67 (0.04)
	13	0.83 (0.01)	21	0.67 (0.04)
	5	0.84 (0.07)	15	0.67 (0.04)
	8	0.85 (0.01)	17	0.67 (0.01)
	18	0.86 (0.02)	14	0.68 (0.02)
	21	0.86 (0.02)	22	0.69 (0.05)
	15	0.89 (0.01)	20	0.71 (0.04)
	Group mean (*SD*)	0.83 (0.03)	Group mean (*SD*)	0.67 (0.02)

CODA task were performed. For the CODA task, players began with their heels placed at the start mark. When ready, the players performed a 180° turn followed immediately by a 2.5-m straight sprint through the second timing light. A 30-second recovery was taken by each player between trials for both tasks. All players were instructed to perform the task as quickly as possible; however, verbal instruction regarding technique was not provided so as to elicit natural acceleration performances from each player.

Data Analysis

Players were ranked based on their 2.5-m times (averaged across 3 trials) and grouped into 2 categories: faster ($n = 11$) and slower ($n = 11$). Video was advanced frame by frame and time-stamped to code the events of interest. Performance times (for the 3 trials) were averaged together for both tasks. Torso angle (from the torso to the vertical; Figure 2), hip angle (from the thigh up to the horizontal) of the free leg at contralateral foot takeoff (Figure 3), and SL were measured for the first 3 steps of both tasks. Average SF was calculated by the time from when the takeoff foot (second foot) left the ground at the start of the sprint to the ground contact of the third step. These 4 variables were of particular interest because they were thought to vary considerably between the 2 tasks, yet be observed by the naked eye for immediate feedback by coaches when analyzing player performances during training sessions. Because data consisted solely of performance times and video analysis, any reference to forces or body weight distribution is purely observational and not the result of force plate data.

Table 2. Kinematic values averaged across groups and tasks presented as the mean (*SD*).*

		SA	CODA
Faster group	SL (m)	1.12 (0.10)†‡	0.89 (0.07)‡
	SF (Hz)	5.45 (0.42)	5.55 (0.21)§
	2.5-m time (s)	0.77 (0.02)	0.62 (0.01)
Slower group	SL (m)	1.20 (0.06)†‡	0.93 (0.05)‡
	SF (Hz)	5.22 (0.26)	5.31 (0.22)§
	2.5-m time (s)	0.83 (0.03)	0.67 (0.02)

*SA = straight acceleration; CODA = change-of-direction acceleration; SL = step length; SF = step frequency.
†Significant difference: fast and slow average SL for the SA task.
‡Significant difference: average SL between SA and CODA tasks.
§Significant difference: fast and slow average SF for the CODA task.

Statistical Analyses

Average performance times, SL, SF, and joint angles were calculated across the 3 trials for SA and CODA. Performance times are presented as means and *SD*. Coefficient of determination (r^2) and independent t-tests were used to compare the faster and slower groups on the variables of interest. Statistical significance was set at $p \leq 0.05$.

Results

The squad rankings for SA and CODA tasks based on 2.5-m times can be observed

Table 3. Average kinematic values of each step for the straight acceleration (SA) and change-of-direction acceleration (CODA) tasks presented as the mean (*SD*).*

		SA			CODA		
		SL (m)†	TOR (°)	HIP (°)	SL (m)†	TOR (°)	HIP (°)
Faster group	1st step	0.95 (0.03)‡	39.3 (6.6)§‖	28.0 (8.4)¶#	0.74 (0.08)	27.5 (6.0)‖	35.4 (10.1)#
	2nd step	1.10 (0.11)‡	37.0 (6.2)	29.3 (5.2)**	0.92 (0.08)	34.6 (4.6)	33.7 (6.0)**
	3rd step	1.31 (0.11)‡	32.3 (4.8)	25.5 (4.0)	1.00 (0.11)	34.8 (3.4)	29.1 (3.4)
Slower group	1st step	1.00 (0.09)‡	38.0 (7.3)§	32.4 (5.7)¶#	0.81 (0.06)	23.9 (7.0)	41.5 (9.4)#
	2nd step	1.21 (0.08)‡	37.3 (7.7)	34.7 (5.3)**	0.99 (0.08)	34.6 (7.3)	37.9 (5.3)**
	3rd step	1.40 (0.09)‡	33.1 (7.3)	29.9 (5.7)	1.03 (0.10)	31.7 (5.1)	31.2 (7.9)

*SL = step length; TOR = torso angle; HIP = hip angle.
†Significant difference: SL between tasks.
‡Significant difference: SL of SA between groups.
§Significant difference: first torso angle of SA between groups.
‖Significant difference: first torso angle between tasks.
¶Significant difference: first hip angle of SA between groups.
#Significant difference: first hip angles between tasks.
**Significant difference: second hip angle between tasks.

in Table 1. Those players with faster 2.5-m times in the SA task did not necessarily perform equally fast in the CODA task ($r^2 = 0.15$). Five of the 22 players dropped from the faster group in the SA task to the slower group in the CODA task, and conversely, 5 players also improved from slower in the SA task to faster in the CODA task.

In terms of the group comparisons, only 1 variable differed significantly between groups for the CODA task. Significantly higher average SF (4%, $p = 0.03$) was observed for the faster group when compared with the slower group (Table 2).

For the SA task, faster times were associated with significantly smaller average SLs (7%, $p = 0.03$), greater torso angles (i.e., greater forward lean; 30–37%, $p < 0.001$), and smaller hip angles (less knee lift) in the first step (21–22%, $p = 0.00$). On average, the faster group had smaller SLs, higher average SF, and a lower knee lift than the slower group.

With regard to the task comparison, the SA task was associated with significantly longer average SLs (21–23%, $p = 0.00$; Table 2) and significantly longer SL across all 3 steps than the CODA task (17–27%, $p < 0.001$; Table 3). Additionally, a significantly larger torso angle was associated with the first step of the SA task (34%, $p < 0.001$) and significantly smaller hip angles for the first and second steps of the SA task (11–22%, $p = 0.00$ and 0.04, respectively).

Discussion

Acceleration in court-based team sports such as netball and basketball is typically confined to a relatively small area, which is defined by boundary lines or opponents. As such, players are often not able to accelerate for >2.5–5 m before an evasive COD is required (22,24). However, the majority of research addressing acceleration technique is from a static start over >5 m (i.e., more reflective of track sprinting ability as opposed to game speed ability) (5,6,10,13–15,18,26). As the objectives of acceleration movements performed across sports vary considerably and the relationship between SA and CODA is typically quite poor (24), it is likely that SA technique also differs considerably from that of the more sport-specific CODA technique. Consequently, the primary purpose of this article was to compare the stride characteristics and body positioning adopted by faster and slower court-based team players during the first 3 strides when accelerating in an SA with those of the acceleration after a rapid 180° ground-based COD movement (i.e., CODA).

When the kinematics (i.e., SL, and hip and torso angles) of each group was compared, several differences were observed between the SA and CODA tasks. Unlike Mann and Herman's (18) findings that reported 3% longer SLs in faster straight sprinting performances, abbreviated (7–8%) average SL and individual SLs were observed in the faster SA performances in the present study. Although average SF was not significantly different between groups for the SA task ($p = 0.13$), it was approaching significance and it may be speculated that the higher SF of the faster group was that which differentiated the 2 groups (i.e., because velocity = SL × SF). In terms of increasing player first step quickness, it would seem that cuing faster SF or conversely teaching players not to overstride may optimize 2.5-m sprint performance.

Although average SFs observed in this study were greater than those reported in previous research (4.01–4.45 Hz (14,18)), the sample of participants and data collection varied greatly to those of the present study. The participants of the current study were female court-based sport players, whereas previous research was conducted using Olympic-level male sprinters (18) and male athletes from various field sports (14). It has been documented that track speed is different to field sport speed (7,8,16,25), with most players achieving maximum velocity in a shorter distance compared with track athletes. As such, it is likely that those athletes that need to accelerate quicker over shorter distances would have different step kinematics (i.e., SF). Additionally, in both of these previous studies, the SFs were calculated during a midsection of a sprint >10 m from the start of the task (to the knowledge of the authors of the current study, no research has investigated acceleration kinematics over 2.5–5 m), whereas the present study reported SFs over the first 3 steps from a static start. These 2 factors likely contributed to the difference in reported SFs.

The faster players also had a higher knee lift (decreased hip angle) and increased torso angle (increased forward lean) in the SA task. A higher knee lift at takeoff would increase the time the free leg is spent in the air, thereby allowing for a larger SL to be attained through each step. However, this was not the case for the faster athletes, and in fact, their SL was significantly less than that of the slower players. It can only be speculated that even though there was higher knee lift, the velocity of limb movement was quicker in the fast group (e.g., SF), the product being a leg that drives down into the ground further, faster, and more rearward. It is likely that greater propulsive ground reaction forces result; however, further analysis (e.g., force plate) would be needed to investigate this contention.

During the acceleration phase of straight-line sprinting, a forward lean of the torso of up to 45° has been reported as being "optimal" (3,5,9) in elite-level sprinters. The SA torso angle in the current study (32.3–39.3°) was similar to that reported in a previous research by Atwater (3) (15–45°) over the first 3 steps of an SA performance in elite sprinters. An increased forward lean (increased torso angle) at takeoff in the SA task assists in the ability to accelerate as the body's center of mass is brought ahead of the base of support. This allows for increased horizontal propulsive forces to be applied into the ground (26) at takeoff.

In terms of the task comparisons, when performing the SA task, all players had longer SLs, increased torso angle for the first step, and decreased hip angles for the first 2 steps than observed for the CODA task. When a player is accelerating after a rapid COD, the free leg must first rotate around into the new direction before driving upward. In contrast, during the SA task, the knee can be driven upward immediately after takeoff. As a result, a higher knee lift (as observed in the SA task) allows more time for the lower leg to extend into a longer SL. The longer the free leg is airborne through the swing phase, the longer it will take before a horizontal or lateral force can be applied into the ground for a COD movement. The increased forward lean associated with the SA task allows for increased stability and horizontal-vertical propulsive forces into the ground at takeoff (26). Therefore, the more erect posture associated with the CODA task (i.e., an abbreviated SL, decreased forward lean, and decreased knee lift) will be more advantageous when performing consecutive COD movements because the free leg is able to be repositioned earlier for the next ground contact.

Consistent with previous research (24), players who performed well in one task did not necessarily perform equally well in the other task (as observed by the low shared variance of performance times and task). This finding is reinforced by the data in Table 1 where quite substantial differences in rankings between the SA and CODA tasks can be observed for some players. The value of such an analysis is in the ability to diagnose athletes who have SA or COD limitations. Identifying either as a problem will thereafter involve very different strategies by the coach and strength and conditioning practitioner to remediate the limitations. That is, an athlete who has a faster sprint time but a slower CODA time would most likely benefit from technique training around changing directions. Conversely, athlete with a slower sprint time would most likely benefit from explosive strength and power type training. With regard to the first scenario, where the CODA time is slower, identifying those technical cues that are predictors of faster performance would seem of practical value. For this to occur, a sport-specific approach using a relevant CODA task would seem prerequisite to identifying those factors that optimize sport-specific COD performance. An assessment tool that more closely resembles the movement characteristics required in competition increases both the validity of the assessment itself and the diagnostic value to the strength and conditioning coach.

This study has not exhaustively investigated the technical characteristics specific to SA and CODA tasks. Insights into the differences in the technical characteristics when performing 2 forms of acceleration tasks for faster and slower players have been identified based off of kinematic data. Those qualities consistently present in faster performances (e.g., more erect posture at takeoff and decreased SL and knee drive for CODA when compared with SA performances) would seem desirable qualities to emphasize in training sessions for all levels of players. Additional research is needed to further examine the technical qualities that contribute to faster sport-specific acceleration performances.

It should be noted that one limitation of this study was that the trials were not randomized. Although the effects of fatigue are likely not an issue with the tasks in this study, it is possible that learning effects may be present. If further research is conducted following the procedures outlined in this study, this learning effect should be taken into account and a randomized trial order is recommended.

Practical Applications

The faster players observed in this study had several kinematic differences between SA and CODA tasks when compared with the slower players. Because these characteristics are associated with more optimal force productions and resulting velocities through the acceleration phase of sprinting, emphasizing those technical characteristics that were associated with the faster players' SA (decreased SL, increased forward lean and knee lift in the initial step) and CODA (increased SF) performances in the training programs of all players would likely improve SA and CODA performances, respectively.

The results from this study also indicate that the technical characteristics of SA are not the same for CODA. The goal of SA is to attain maximum velocity as quickly as possible. In contrast, CODA requires players to accelerate as quickly as possible after a rapid directional change and may also occur before a subsequent COD movement. As a result, the body positioning and posture differ greatly between the 2 acceleration tasks (i.e., a more erect posture at takeoff and decreased SL and knee drive for CODA when compared with SA performances). Task-specific training programs that target these features may lead to improved performance times in each respective task and possibly increase transference into the sport.

When group means are compared, a great deal of information regarding individual player strengths and weaknesses is lost. Investigating the intersquad player rankings in various tasks (i.e., SA vs. CODA) can give insights into the task-specific capabilities of players and areas in need of improvement within the movement sequence. Likewise, when raw kinematic values of players are compared, individual technical weaknesses may be identified. As a result, programming can be guided to a better effect. Although this study investigated only 4 kinematic features of SA and CODA performances, additional research that examines these characteristics and additional kinematic variables (e.g., knee angle at touchdown) over a variety of movement tasks that are commonly performed in sport will further increase our understanding of training and programming for acceleration in sport.

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