©Journal of Sports Science and Medicine (2012) **11**, 444-451
http://www.jssm.org

Research article

Kinematics of the typical beach flags start for young adult sprinters

Robert G. Lockie ✉, **William M. Vickery and Xanne A.K. Janse de Jonge**
Exercise and Sport Science, School of Environmental and Life Sciences, University of Newcastle, Australia

Abstract
This study profiled beach flags start kinematics for experienced young adult sprinters. Five males and three females (age = 20.8 ± 2.1 years; height = 1.70 ± 0.06 meters [m]; mass = 63.9 ± 6.0 kilograms) completed four sprints using their competition start technique. A high-speed camera, positioned laterally, filmed the start. Data included: start time; hand clearance time; posterior movement from the start line; feet spacing during the start; elbow, hip, knee, trunk lean, and trajectory angles at take-off; and first step length. Timing gates recorded 0-2, 0-5, and 0-20 m time. Spearman's correlations identified variables relating ($p \leq 0.05$) to faster start and sprint times. The beach flags start involved sprinters moving 0.18 ± 0.05 m posterior to the start line by flexing both legs underneath the body before turning. Following the turn, the feet were positioned 0.47 ± 0.07 apart. This distance negatively correlated with start (ρ = -0.647), 0-2 (ρ = -0.683), and 0-5 m (ρ = -0.766) time. Beach flags start kinematics at take-off resembled research analyzing track starts and acceleration. The elbow extension angle (137.62 ± 13.45°) of the opposite arm to the drive leg correlated with 0-2 (ρ = -0.762), 0-5 (ρ = -0.810), and 0-20 m (ρ = -0.810) time. Greater arm extension likely assisted with stability during the start, leading to enhanced sprint performance. The drive leg knee extension angle (146.36 ± 2.26°) correlated with start time (ρ = -0.677), indicating a contribution to a faster start completion. A longer first step following the start related to faster 0-5 m time (ρ = -0.690). Sprinters quicker over 0-2 and 0-5 m were also quicker over 20 m (ρ = 0.881-0.952). Beach flags sprinters must ensure their start is completed quickly, such that they can attain a high speed throughout the race.

Key words: Biomechanics, surf lifesaving, sprint start, acceleration, beach sprinting.

Introduction

The beach flags are a popular surf lifesaving event comprised of a series of elimination rounds involving 20-metre (m) sprints across soft beach sand, the aim of which is for the sprinter to attain a flag positioned in the sand ahead of their opponents. Elimination rounds continue until there is one remaining athlete who is declared the winner. A feature of this event is its unique start. The sprinters begin the event in a prone position with their feet placed on the start line, facing the opposite direction to where the flags are positioned vertically in the sand surface in a line at the finish line. Upon the start command, sprinters turn as quickly as possible to face the flags and begin their run. An effective start is essential for beach flags performance (MacDonald, 2007). The instability caused by the sand surface is a major issue in achieving an effective start for beach sprinters. Sand contains higher absorptive qualities than a surface such as grass (Zamparo et al., 1992), and movements on sand surfaces feature reduced energy recovery, and a decrease in muscle work efficiency (Davis and MacKinnon, 2006; Zamparo et al., 1992). The quality of the sand (i.e. wet vs. dry sand) may also have an impact upon force generation and sprint performance. It is likely that there are specific movement patterns adopted by beach flags sprinters to make their starts more effective.

There has been widespread analysis of the sprint start used by track sprinters (Harland and Steele, 1997). Unfortunately, the same cannot be said for the beach flags start. There are limitations when applying track start information to beach flags sprinters, in that they do not use starting blocks, nor do they compete on an athletics track. The prone starting position and turn are also specific to the beach flags. Nonetheless, in order to develop an understanding of an effective beach sprint start, it is pertinent to understand the characteristics of a track sprint start due to the lack of research with beach flags. The total duration for a start (from initial force production until loss of contact of the front leg with the starting blocks) in elite sprinters is approximately 0.34-0.39 seconds (s) in a 100-m sprint (Bradshaw et al., 2007; Mero et al., 2006), and accounts for 5% of the total sprint time (Tellez and Doolittle, 1984). Due to the movement patterns involved in the beach flags start (i.e. elevating and rotating the body from a prone position), it would be expected that the duration of the start would be longer when compared to track starts. The importance of the start would be more apparent during a shorter sprint event such as beach flags, where the start accounts for 26% of the total sprint time (MacDonald, 2007). Indeed, a faster beach flags start could allow a sprinter to move ahead of his competitors during the early stages of a race.

This is a notable issue, as an effective sprint start should place an athlete into a position that allows for great acceleration. Block spacing, which is the distance between the feet in the 'set' position, is an important consideration for track starts as it can affect the duration of force development (Guissard et al., 1992; Schot and Knutzen, 1992). Following the turn in the beach flags start, the sprinter will be in a position where both their feet are in contact with the ground, and the direction and spacing between them could affect how efficient the start is. Čoh et al. (2006) recommends the use of a medium start position, which is a distance between the feet of 0.4-0.5 m. In contrast, Schot and Knutzen (1992) advocated an elongated start position of approximately 0.8 m. There are also certain technique characteristics at take-off that are synonymous with effective track starts. A complete

Received: 13 February 2012 / Accepted: 25 May 2012 / Published (online): 01 September 2012

and powerful extension of the drive leg during a track start has been recommended (van Ingen Schenau et al., 1994). A greater trunk lean during the start has a positive influence on take-off speed (Atwater, 1982; Bradshaw et al., 2007), as it allows for an emphasis on horizontal force production (Harland et al., 1995). An angle of trajectory, or total body take-off angle, closer to the horizontal has been correlated to faster sprint times (Čoh et al., 1998). While it is envisaged that a beach flags sprinter at start take-off will demonstrate some of these kinematic characteristics, there is no research that documents whether this actually occurs.

Therefore, the purpose of the current study is to determine the kinematic profile, which will encompass temporal characteristics, and joint and body positions during the start, of experienced young adult beach flags sprinters. 0-2 m, 0-5 m, and 0-20 m, sprint times that follow a traditional beach flags start will also be documented. It is hypothesized that the beach flags start will feature specific technique characteristics when compared to previous research detailing track sprint starts. This will include factors such as relatively longer total start time, posterior movement behind the start line to facilitate the turn, and different take-off kinematics (e.g. a more vertical trunk lean and angle of trajectory because of the unstable sand surface). This study will also determine the relationship between the mechanics of the beach flags start and sprint performance. Spearman's rank order correlations will be assessed between start kinematics and sprint times to establish start technique variables that impact the beach flags sprint. It is hypothesized that faster sprint times will be associated with particular technique parameters, including a faster start time, less posterior movement behind the start line, and a wider distance between the feet during the start to assist with balance following the turn. It is further hypothesized that faster sprint performances will be related to certain kinematic parameters at start take-off, including greater hip and knee extension of the drive leg, greater hip and knee flexion of the swing leg, greater range of motion at the arms to counterbalance the leg actions, and a more horizontally inclined trunk lean and angle of trajectory.

Methods

Subjects

Young adult sprinters currently active in beach flags competition at a regional or national level of competition were recruited for this study. Eight subjects (five males and three females; mean age = 20.8 ± 2.1 years; height = 1.70 ± 0.06 m; mass = 63.9 ± 6.0 kilograms [kg]) volunteered for this study. Previous research has analyzed sprint technique and performance with mixed-gender subject groups (Eikenberry et al., 2008; Guissard et al., 1992; Schot and Knutzen, 1992). As long as subjects display similar trends in technique during the start (Guissard et al., 1992), male and female sprinters can be grouped for analysis. The use of eight subjects is similar to (Bradshaw et al., 2007; Mero et al., 2006) or exceeds (Čoh et al., 2006; Merni et al., 1992) previous sprint start research. The methodology and procedures used in this study were approved by the institutional ethics committee, and conformed to the policy statement with respect to the Declaration of Helsinki. All participants received a clear explanation of the study, including the risks and benefits of participation, and written informed consent was obtained prior to testing.

Testing procedures

Testing was conducted on beaches in New South Wales, Australia. To ensure consistency, testing days of comparable weather conditions and a level section of dry, sandy beach were used. Given that different sand conditions could affect sprint performance, great care was taken to ensure similar surface conditions were used across all testing sessions. Subjects wore competition attire, consisting of swimming costumes. Prior to testing, leg dominance was defined for each subject, due to the suggested importance of positioning the dominant leg in either the front or rear block for track sprinting (Čoh et al., 2006; Harland and Steele, 1997; Vagenas and Hoshizaki, 1986). Leg dominance was assessed through three standard clinical tests (de Ruiter et al., 2010). The first test involved subjects stepping up on a 40-centimeter platform; the leading leg was viewed as dominant. The second test involved subjects standing with feet parallel before being pushed between the shoulder blades by one of the researchers. The leg used to prevent the fall was considered dominant. Lastly, subjects were asked their preferred kicking leg; this leg was deemed dominant. The dominant leg was classified as the leg that was dominant in at least two of three tests. Subjects then completed an identical warm-up routine which consisted of jogging, dynamic stretches, and acceleration runs over the testing distance. Four successful trials of the sprint protocol detailed in the methodology were obtained for each subject, with three minutes recovery between trials. The average of the kinematic data derived from these trials was used for analysis.

Kinematic analysis

The equipment set-up for the assessment of the beach flags start and sprint performance is shown in Figure 1. The 20-m sprint distance is in accordance with and adapted from the protocols recommended by Surf Life Saving Australia (SLSA) when testing beach flags sprinters (SLSA, 2005). Sprint times were recorded for the 0-2 m, 0-5 m, and 0-20 m intervals through the use of timing gates (Smartspeed, Fusion Sport, Australia), which were synchronized with a handheld computer (iPAQ, Hewlett-Packard, USA) which collected the data. Timing gates were placed at 2 m and 20 m as per SLSA guidelines (SLSA, 2005), while another gate was placed at 5 m to record the initial acceleration ability of the subjects (Cronin and Hansen, 2005, Lockie et al., 2011). The other gate was positioned next to the starter, who initiated timing by passing their hand through the light beam. This novel timing technique was utilized due to the prone starting position inherent to the beach flags, which made it difficult to use other gate positions to initiate timing. Subjects were given the standard set of commands that are used during beach flags competition. These were: (1)

you are in the starter's hands, (2) heads down, and (3) the starter then blew a whistle to start the sprint while simultaneously initiating the timing gate system. Subjects sprinted past the final timing gate and were instructed not to slow down prior to the finish line. This was achieved by placing a target line 5 m beyond the final gate. If subjects started prior to the whistle, the trial was disregarded and another attempt was allowed after the recovery period.

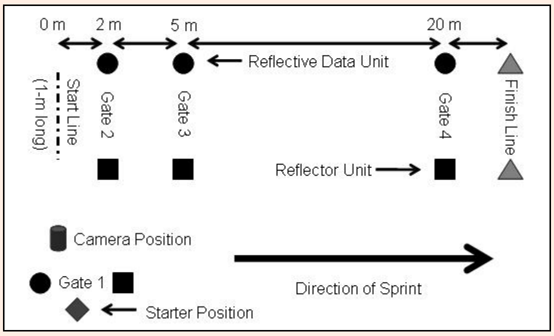

Figure 1. Equipment set-up for the assessment of the beach flags start and sprint. m = meters.

A high-speed camera (piA640-210gc, Baslar Vision Technologies, Germany), with a frame rate of 100 Hertz, was connected to a laptop computer (PP18L, Dell, USA) and recorded the start. Both the camera and laptop received power using a 300-watt portable invertor (PureWatt, Sinergex Technologies, USA), which was connected to a deep-cycle battery. The camera was placed perpendicular to the start line, 5.5 m lateral to the participant (Figure 1). This position recorded sagittal plane movements, and the camera was situated on the side the participant turned towards during their start and calibrated prior to testing. Black, hemispherical markers were placed on both sides of the body on the following anatomical landmarks: acromion process (shoulder); lateral epicondyle of the ulna (elbow); midpoint of the styloid process of the radius and ulna (wrist); greater trochanter of the femur (hip); lateral epicondyle of the femur (knee); lateral malleolus of the fibula (ankle); and fifth metatarsal (toe).

The recordings from the camera were analyzed within motion analysis software (Dartfish 5.0, Dartfish Video Software Solutions, Australia). The temporal characteristics calculated from the start included the hand clearance time (period from the initiation of movement until the hands break contact with the ground); and start time (period from the initiation of movement until the foot of the driving leg breaks contact with the ground) (Bradshaw et al., 2007). The distance of any posterior movement of the legs behind the start line prior to take-off, and the maximum distance between the feet during the start following the turn, was measured. Kinematic variables analyzed during the sprint start include knee, hip, and elbow joint angles, and trunk segment relative to the vertical angle (Figure 2). First step length following the start, which was the distance from the point of take-off of the driving foot until the point of touchdown of the opposing foot was also measured (Lockie et al., 2011; Murphy et al., 2003).

Statistical analyses

Due to the novel nature of the speed testing protocol, trial-to-trial reliability of sprint times measured within the study was assessed by intra-class correlation coefficients (ICC) calculated from a two-way mixed method consistency model for single measures (Lockie et al., 2011, Markovic et al., 2004). An ICC equal to or above 0.70 was considered acceptable (Baumgartner and Chung, 2001; Hori et al., 2009). Cronbach's Alpha (CA) was also computed for the reliability analysis. The typical error of measurement (TEM) was calculated through the formula: *TEM = Standard Deviation ÷ √(1 – ICC)*. A TEM value less than 0.2 s, which has been defined as the smallest worthwhile change in sprint times (Duthie et al., 2006), was considered acceptable for this study. A Spearman's rank order correlation analysis ($p \leq 0.05$) was conducted to determine the relationships between start technique variables and sprint times. For the purpose of this study, a Spearman's rho (ρ) value less than 0.7 was considered low; 0.71 to 0.9 moderate; and 0.91 and higher good for predicting relationships (Vincent, 1995). All statistical analyses were processed using the Statistics Package for Social Sciences (Version 20.0; IBM Corporation, New York, USA).

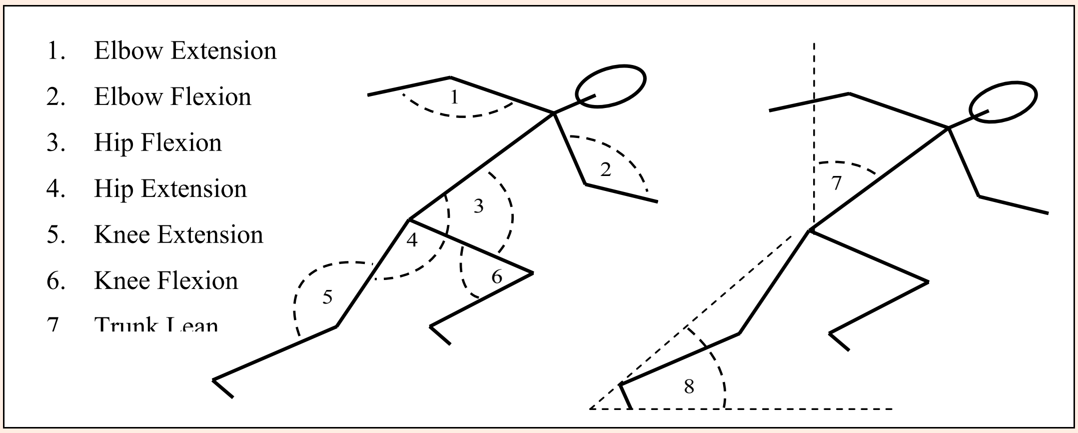

Figure 2. Joint kinematics measured during the beach flags start.

Figure 3. **Sequence of a typical beach flags start for young adult sprinters.**

Results

Start technique and sprint times

As all subjects displayed similar trends in start kinematics, data was grouped for male and female sprinters in this analysis. The typical start technique can be seen in Figure 3. The start involved flexion of the hips and knees to move both legs underneath the torso prior to the turn, which caused the legs and feet to move posterior to the start-line. The shank of the non-driving, rear leg remained in contact with the sand for a short period of time to aid push-off from the ground. Table 1 displays the kinematics of the beach flags start for young adult sprinters. Times included hand clearance time, start time, and times for the 0-2 m, 0-5 m, and 0-20 m sprint intervals. The reliability for time calculated within each of the sprint intervals (0-2 m: ICC = 0.77, CA = 0.93, TEM = 0.11 s; 0-5 m: ICC = 0.81, CA = 0.95, TEM = 0.11 s; 0-20 m: ICC = 0.93, CA = 0.98, TEM = 0.11 s) was considered acceptable for this study. The specific distances recorded for beach flags start included the posterior foot movement, between-feet distance following the turn, and the first step length following the start (Table 1). Table 1 also presents the joint kinematics of the body at take-off from the start. The placement of each foot whilst in the maximum foot width position (i.e. front and rear legs) was noted in relation to the clinically-defined dominant leg of each subject (Table 2). Two subjects used their dominant leg as the front, driving leg during the start. The other six subjects all positioned the dominant leg at the rear following the turn.

Correlations

Start time, and time over the 0-2 m, 0-5 m, and 0-20 m intervals, was correlated with all kinematic variables measured in the current study (Table 3). Significant positive correlations were evident between the 0-2 m time, and the 0-5 m (ρ = 0.952; $p < 0.001$) and 0-20 m (ρ = 0.929; $p < 0.001$) times. A positive correlation was also found between the 0-5 m and 0-20 m time (ρ = 0.881; p = 0.002). There were significant negative correlations between the maximum distance between the feet and start time (ρ = -0.647; p = 0.042), and time in the 0-2 m (ρ = -0.683; p = 0.031), and 0-5 m (ρ = -0.766; p = 0.013) intervals. Significant relationships were evident between the elbow extension angle of the arm opposing the swing leg, and time in each of the sprint intervals (0-2 m: ρ = -0.762, p = 0.014; 0-5 m: ρ = -0.810, p = 0.007; 0-20 m: ρ = -0.810, p = 0.007). Start time and knee extension of the drive leg were negatively correlated (ρ = -0.677; p = 0.035). First step length had a negative correlation with 0-5 m time (ρ = -0.690;p = 0.029).

Table 1. **Temporal and distance characteristics, and joint kinematics at take-off for the beach flags start for young adult sprinters. Data are means (±standard deviation).**

Kinematic Data	Data (n = 8)
Times (s)	
Hand Clearance Time	.49 (.18)
Start Time	.72 (.32)
0-2 m Interval	1.45 (.22)
0-5 m Interval	2.08 (.26)
0-20 m Interval	3.75 (.52)
Distances (m)	
Posterior Foot Movement	.18 (.05)
Front and Rear Foot Distance	.47 (.07)
First Step Length	.53 (.09)
Joint Kinematics at Take-off (°)	
Rear Arm Elbow Extension	137.6 (13.5)
Front Arm Elbow Flexion	71.8 (36.2)
Swing Leg Hip Flexion	82.1 (14.9)
Swing Leg Knee Flexion	91.0 (9.6)
Drive Leg Hip Extension	157.6 (20.5)
Drive Leg Knee Extension	146.4 (2.3)
Trunk Lean	42.0 (16.9)
Angle of Trajectory	51.7 (4.4)

s = seconds; m = meters; ° = degrees.

Table 2. **Dominant leg position during the beach flags start for young adult sprinters.**

Subject	Dominant Leg	Front Leg at Take-off
1	Right	Left
2	Right	Left
3	Right	Right
4	Right	Left
5	Left	Left
6	Right	Left
7	Right	Left
8	Right	Left

Discussion

This is the first investigation on the start kinematics of experienced young adult sprinters who compete in the beach flags event in surf lifesaving. There are several notable aspects to the beach flags start. The duration of the beach flags start (0.72 ± 0.32 s) far exceeds that of the

Table 3. Spearman's rank order correlations between start, 0-2 meter (m), 0-5 m, and 0-20 m time for a 20-m sprint following a beach flags start, and beach flags start kinematics for young adult sprinters.

		Start Time	0-2 m Time	0-5 m Time	0-20 m Time
0-2 m Time	ρ	.238	-	-	-
	p	.285	-	-	-
0-5 m Time	ρ	.214	.952	-	-
	p	.305	.000 *	-	-
0-20 m Time	ρ	-.024	.929	.881	-
	p	.478	.000*	.002 *	-
Hand Clearance Time	ρ	.048	.383	.395	.551
	p	.455	.174	.166	.079
Posterior Foot Movement	ρ	-.048	.333	.476	.452
	p	.455	.210	.116	.130
Front and Rear Foot Distance	ρ	-.647	-.683	-.766	-.551
	p	.042 *	.031 *	.013 *	.079
Rear Elbow Extension	ρ	-.095	-.762	-.810	-.810
	p	.411	.014*	.007 *	.007 *
Front Elbow Flexion	ρ	.405	-.286	-.286	-.381
	p	.160	.246	.246	.176
Swing Leg Hip Flexion	ρ	.071	.238	.024	.095
	p	.433	.285	.478	.411
Swing Leg Knee Flexion	ρ	.524	.619	.524	.619
	p	.091	.051	.091	.051
Drive Leg Hip Extension	ρ	-.429	-.381	-.524	-.357
	p	.145	.176	.091	.193
Drive Leg Knee Extension	ρ	-.677	-.286	-.286	-.024
	p	.035 *	.246	.246	.478
Trunk Lean	ρ	-.143	-.286	-.024	-.214
	p	.368	.246	.478	.305
Angle of Trajectory	ρ	-.333	.619	.524	.619
	p	.210	.051	.091	.051
First Step Length	ρ	-.190	-.619	-.690	-.405
	p	.326	.051	.029 *	.160

Spearman's rho = ρ; significance = p; n = 8. * Significant ($p \leq 0.05$) relationship between the two variables.

traditional track start. Block times in track sprinting are approximately half this duration (Bradshaw et al., 2007; Mero et al., 2006). The actions of the beach flags start would no doubt contribute to this, in that the sprinter needs to rise from a prone position, before turning around to begin their sprint. One of the unique components of the beach flags start was the use of the upper body to push the sprinter from the ground prior to turning and sprinting, and even the time taken to clear the hands during the start exceeded traditional block times (Table 1). Nevertheless, efficient completion of the movements required within the beach flags start should ensure that the sprint is initiated quickly.

Another notable aspect of the beach flags start was the posterior movement of the feet behind the start line prior to the sprint (Table 1). This posterior movement need not be considered a negative technique adaptation. Indeed, the use of a backwards step to initiate forwards acceleration does not adversely affect sprint performance over short distances (Frost and Cronin, 2011). Kraan et al. (2001) outlines some of the mechanisms involved with this concept, in that an initial backwards step when sprinting from a standing start increases the kinetic energy of the movement, and contributes positively to force generation. This would be of benefit for beach flags sprinters, given that there is a decrease in the use of muscular elastic energy because of the surface instability of the sand (Davis and MacKinnon, 2006; Zamparo et al., 1992). Moreover, Frost and Cronin (2011) suggests that the stretch-shortening capacities of the leg muscles may be invoked to a greater extent with an initial backwards step prior to a sprint. If sand takes away some of the sprinter's capacity to use elastic energy, incorporating a posterior movement and backwards step during the beach flags start may help recover some of the lost energy due to surface instability.

The distance between the feet within the blocks in the track start 'set' position can have a large effect on force production and take-off velocity (Harland and Steele, 1997; Schot and Knutzen, 1992). Although beach flags sprinters do not use starting blocks, the repositioning of the lower limbs during the turn can produce a foot position similar to the 'set' position. The average foot spacing for young adult beach flags sprinters was 0.47 ± 0.07 m (Table 1), which is similar to a medium block spacing in track starts (Čoh et al., 2006). Interestingly, this distance negatively correlated with start time, and 0-2 m (ρ = -0.647) and 0-5 m (ρ = -0.683) sprint times (Table 3), although the predictive relationships were relatively low. A moderate relationship was present for the between-feet distance and 0-5 m time (ρ = -0.766). Each of these relationships suggested that a longer distance between the feet during the beach flags start contributed to faster start and sprint times within the first 5 m. The findings from this study may mirror recommendations by Schot and Knutzen (1992), in that an elongated-type 'set' position could be best for generating propulsive force. This could then contribute to a reduced start time, and faster early sprint performance.

More effective sprint starts have been obtained when track sprinters place their dominant foot in the front starting block (Vagenas and Hoshizaki, 1986). This is primarily due to the notion that the dominant leg is stronger, and as it spends more time in contact with the blocks generating force during the start, will ultimately enhance early acceleration. However, the rear leg is the first to respond to the start stimulus in the track start (Mero and Komi, 1990). Within the beach flags start, the rear leg also undergoes the greatest range of motion during the turn, as it is flexed underneath the torso away from the start line, and positioned at the rear (Figure 1). Six from eight subjects placed their clinically-defined dominant leg, which was the right leg, in the rear position (Table 3). Eikenberry et al. (2008) found that positioning the right leg in the rear block position, which was the preferred leg for most of their subject group, resulted in reduced movement time during the start in collegiate sprinters. Furthermore, Ross et al. (2004) intimates that the dominant leg has greater proprioceptive function than the non-dominant leg, and this assists with stability in dynamic skills. As the dominant leg for the majority of subjects from the current study underwent the greatest range of motion during the turn, the proprioceptive capabilities of this leg may have assisted with this movement, as well as maintaining balance on the unstable sand surface following the turn in the beach flags start.

The elbow extension (137.62 ± 13.45º) and flexion (71.82 ± 36.23°) angles resulting at the point of take-off from the beach flags start are similar to those established by elite sprinters (Mann, 1985) and field sport athletes (Lockie et al., 2003; Murphy et al., 2003) during acceleration. In line with the studies hypothesis, elbow range of motion was linked to sprint performance. There were negative correlations, with moderate predictive relationships, between the extension of the rear arm at take-off and 0-2 m (ρ = -0.762), 0-5 m (ρ = -0.810), and 0-20 m (ρ = -0.810) time. These results indicated that subjects with lower sprint times extended their rear arm to a greater extent. This may be linked to flexion of the swing leg, as the arms must be coordinated with the legs to produce efficient movements during the sprint start (Mero et al., 1986). In addition, the action of the arms in a dynamic movement such as the beach flags start would serve to balance any angular momentum generated by the lower body (Hinrichs, 1987). Given that a beach flags sprinter must rotate their entire body during the start, a greater extension of the rear arm may serve to improve stability at start take-off from the beach flags start. This could then enhance the subsequent sprint performance.

Mean swing leg hip flexion angles at take-off from the beach flags start for young adult sprinters was 82.13 ± 14.92º, while the knee flexion angle was 91.00 ± 9.57° (Table 2). This knee flexion angle is slightly greater than the knee flexion angles of 87 ± 7.9° recorded by Merni et al. (1992) from track sprinters, but similar to those recorded by Pinnington et al. (2005) during sand running (90.4 ± 9.1°). Although there were no significant relationships found between the swing leg at take-off and sprint times, the range of motion of the swing leg is an important consideration for the beach flags start. A greater range could allow for a greater increment of internal work for force generation. Further to this, a higher degree of knee flexion causes sprinters to adopt a more forward trunk lean (Pinnington et al., 2005). This would bring the total body center of gravity closer to the hip joint, which may make the sprinter more balanced at take-off.

The mean hip extension angles at take-off from the beach flags start equaled 157.61 ± 20.54º (Table 2). This was greater than data recorded by Merni et al. (1992), who found track sprinters had a hip extension take-off angle of approximately 144°. A full extension of the knee at take-off wasn't achieved from the beach flags start by young adult sprinters (mean = 146.36 ± 2.26°). This is similar to previous research that has analyzed the track sprint start (Merni et al., 1992), and the initial acceleration of field sport athletes (Murphy et al., 2003). Interestingly, a negative correlation was found between the knee extension of the drive leg and start time (ρ = -0.677), suggesting that a greater knee extension was associated with a faster start time. Extending the knee to a greater extent could cause a more vigorous push off from the ground. This could then allow for a faster completion of the start.

A greater trunk lean has been found to have a positive influence on take-off velocity from a track start (Atwater, 1982). In support of the studies hypothesis, young adult beach flags sprinters achieved a trunk lean of 42.04 ± 16.87°, which was noticeably less than previous measures established for track sprinters leaving the starting blocks (~66°) (Atwater, 1982; Bradshaw et al., 2007). The mechanics of the beach flags start in that there are no starting blocks used, in conjunction with the instability provided by the sand surface, would have contributed the relatively more upright body position. However, the beach flags trunk lean angle at start take-off was greater than that recorded for field sport athletes when accelerating from a standing start (~39°) (Lockie et al., 2003). The angle of trajectory at which track sprinters leave the starting blocks is approximately 40-50º (Čoh et al., 1998; Bradshaw et al., 2007). Subjects from the current study produced an angle of trajectory that was slightly above this range (51.68 ± 4.39º). Again, not using starting blocks, combined with the sand surface, would contribute to this slightly more upright body position of young adult beach flags sprinters when compared to track sprinters.

A relatively longer first step out of the starting blocks has been recommended for track sprint starts (Schot and Knutzen, 1992). Track sprinters using starting blocks can have a first step length of approximately 1 m (Bradshaw et al., 2007; Čoh et al., 2006). The first step that results from a beach flags start is less than that, with a value of 0.53 ± 0.09 m recorded in the current study. Nevertheless, a longer first step following the start may benefit performance in the early stages of a beach flags sprint. A significant negative correlation was seen between the first step length and time in the 0-5 m interval (Table 3). Although the predictive relationship that suggested a longer step was associated with a faster 0-5 m time was relatively low (ρ = -0.690), these results still provide impetus to the need for a beach flags sprinter to establish an advantage within the first few meters of the sprint. A longer first step could place a beach flags sprinter ahead of their competitors through these initial stages.

The sprint times achieved by beach flags sprinters over the three intervals used in the current study were slower than values previously established within the literature. For track sprint athletes using block starts, the time taken to cover the initial 2 m is less than 0.5 s (Schot and Knutzen, 1992, Čoh et al., 2006). Subjects from the current study far exceeded this value (Table 1). Experienced track sprinters (Čoh et al., 1998) and faster field sport athletes (Lockie et al., 2011) can cover 5 m in approximately 1.2-1.3 s, while young adult beach flags sprinters covered the 0-5 m interval in approximately 2 s. Experienced track sprinters can complete the 0-20 m interval of a sprint in 2.86-3.33 s (Čoh et al., 1998; 2006), while young adult beach flags sprinters were in excess of 3 s. The methodology adopted in the current study would have affected the recorded times, as the entire duration of the start was encompassed within the time measurement for each sprint, in that the starter 'broke' the first gate to initiate the sprint. The sand surface on which the beach flags sprinters compete would also affect sprint performance, as there can be a lack of foot compliance which slows movement speed when performing dynamic activities (Giatsis et al., 2004). Nevertheless, the results of this study demonstrate the times achieved by experienced, young adult beach flags sprinters using their competition start technique.

There were moderate to large predictive correlations (ρ = 0.881-0.952) between the times from the sprint intervals in the current study (Table 3). This indicates that those sprinters who had lower times over 0-2 m interval also had lower times for the 0-5 and 0-20 m intervals. This was also true when correlating 0-5 m and 0-20 m sprint times. When considering rugby union players, Cronin and Hansen (2005) found that those athletes who were significantly faster over the first 5 m of a sprint were also faster at 10 m and 30 m. Therefore, to be successful in the beach flags, the sprinter must be quicker in the initial stages of the sprint, and maintain this over the entire distance. This, in conjunction with effective start kinematics such as appropriate range of motion at the arms and legs, should lead to successful performance within the beach flags.

Conclusion

There are several practical implications that can be provided to beach flags sprinters and coaches following this research. Beach flags sprinters tend to move in a posterior direction from the start line following the turn during the start. This may assist with force generation and elastic energy usage for take-off. A greater distance between the feet following the turn correlated with lower sprint times, and this could be linked to advantageous force generation. The joint kinematics adopted at take-off must allow the sprinter to remain balanced on the sand surface, while also leading to a body position that can transition into a fast sprint. The range of motion at the arms, especially the arm opposite to the swing leg, can help stabilize the body through the turn and initial leg drive. Greater knee extension of the drive leg could assist with reducing start time. A longer first step following the start helps reduce time over the 0-5 m interval of a 20-m sprint. Beach flags sprinters must ensure a high sprinting velocity throughout all sections of the race. Future research should use a greater number of subjects, which could allow for analysis of potential differences in the start technique used by beach flags sprinters. Incorporation of ground reaction force data, as well as three-dimensional motion analysis to encapsulate the rotational elements of the skill, would also be pertinent.

Acknowledgements

Thank you to Renee Lavery and Alex Templeton from SLSA for facilitating the testing. We would like to acknowledge our subjects for their contribution to the study. This research project received no external financial assistance. None of the authors have any conflict of interest.

References

Atwater, A.E. (1982) Kinematic analyses of sprinting. *Track & Field Quarterly Review* **82,** 12-16.

Baumgartner, T.A. and Chung, H. (2001) Confidence limits for intraclass reliability coefficients. *Measurement in Physical Education and Exercise Science* **5,** 179-188.

Bradshaw, E.J., Maulder, P.S. and Keogh, J.W. (2007) Biological movement variability during the sprint start: performance enhancement or hindrance? *Sports Biomechanics* **6,** 246-260.

Čoh, M., Jošt, B., Škof, B., Tomažin, K. and Dolenec, A. (1998) Kinematic and kinetic parameters of the sprint start and start acceleration model of top sprinters. *Gymnica* **28,** 33-42.

Čoh, M., Tomažin, K. and Štuhec, S. (2006) The biomechanical model of the sprint start and block acceleration. *Physical Education and Sport* **4,** 103-114.

Cronin, J.B. and Hansen, K.T. (2005) Strength and power predictors of sports speed. *Journal of Strength and Conditioning Research* **19,** 349-357.

Davis, S.E.H. and Mackinnon, S.N. (2006) The energetics of walking on sand and grass at various speeds. *Ergonomics* **49,** 651-660.

De Ruiter, C.J., De Korte, A., Schreven, S. and De Haan, A. (2010) Leg dominancy in relation to fast isometric torque production and squat jump height. *European Journal of Applied Physiology* **108(2),** 247-255.

Duthie, G.M., Pyne, D.B., Ross, A.A., Livingstone, S.G. and Hooper, S.L. (2006) The reliability of ten-meter sprint time using different starting techniques. *Journal of Strength and Conditioning Research* **20,** 246-251.

Eikenberry, A., Mcauliffe, J., Welsh, T.N., Zerpa, C., Mcpherson, M. and Newhouse, I. (2008) Starting with the "right" foot minimizes sprint start time. *Acta Physiologica Scandinavica* **127,** 495-500.

Frost, D.M. and Cronin, J.B. (2011) Stepping back to improve sprint performance: a kinetic analysis of the first step forwards. *Journal of Strength and Conditioning Research* **25,** 2721-2728.

Giatsis, G., Kollias, I., Panoutsakopoulos, V. and Papaiakovou, G. (2004) Biomechanical differences in elite beach-volleyball players in vertical squat jump on rigid and sand surface. *Sports Biomechanics* **3,** 145-158.

Guissard, N., Duchateau, J. and Hainaut, K. (1992) EMG and mechanical changes during sprint starts at different front block obliquities. *Medicine and Science in Sports and Exercise* **24,** 1257-1263.

Harland, M.J. and Steele, J.R. (1997) Biomechanics of the sprint start. *Sports Medicine* **23,** 11-20.

Harland, M.J., Steele, J.R. and Andrews, M.H. (1995) The sprint start: a kinetic and kinematic comparison of slow versus fast starters. In: *XVth Congress of the International Society of Biomechanics, July 2-6, 1995, Jyvaskyla: book of abstracts.* Ed: Hakkinen, K. Jyvaskyla, University of Jyvaskyla.

Hinrichs, R. N. (1987) Upper extremity function in running. II: Angular momentum considerations. *International Journal of Sport Biomechanics* **3,** 242-263.

Hori, N., Newton, R.U., Kawamori, N., Mcguigan, M.R., Kraemer, W.J. and Nosaka, K. (2009) Reliability of performance measurements derived from ground reaction force data during countermovement jump and the influence of sampling frequency. *Journal of Strength and Conditioning Research* **23,** 874-882.

Kraan, G.A., Van Veen, J., Snijders, C.J. and Storm, J. (2001) Starting from standing; why step backwards? *Journal of Biomechanics* **34,** 211-215.

Lockie, R.G., Murphy, A.J., Knight, T.J. and Janse De Jonge, X.A.K. (2011) Factors that differentiate acceleration ability in field sport athletes. *Journal of Strength and Conditioning Research* **25,** 2704-2714.

Lockie, R.G., Murphy, A.J. and Spinks, C.D. (2003) Effects of resisted sled towing on sprint kinematics in field-sport athletes. *Journal of Strength and Conditioning Research* **17,** 760-767.

Macdonald, M. (2007) Beach Events Coaching Programme 2007.

Mann, R. (1985) Biomechanical analysis of the elite sprinter and hurdler. In: *The Elite Athlete.* Eds: Butts, N.K. and Gushiken, T.T. New York, SP Medical and Scientific Books.

Markovic, G., Dizdar, D., Jukic, I. and Cardinale, M. (2004) Reliability and factorial validity of squat and countermovement jump tests. *Journal of Strength and Conditioning Research* **18,** 551-555.

Merni, F., Cicchella, A., Bombardi, F., Ciacci, S., Magenti, L., Olmucci, S. and Coppini, L. (1992) Kinematic and dynamic analysis of sprint start. In: *ISBS '92 Proceedings of the 10th Symposium of the International Society of Biomechanics in Sports.* Ed: Rodano, R. Milan, Edi-Ermes.

Mero, A. and Komi, P.V. (1990) Reaction time and electromyographic activity during a sprint start. *European Journal of Applied Physiology and Occupational Physiology* **61,** 73-80.

Mero, A., Kuitunen, S., Harland, M., Kyrolainen, H. and Komi, P.V. (2006) Effects of muscle-tendon length on joint moment and power during sprint starts. *Journal of Sports Sciences* **24,** 165-173.

Mero, A., Luhtanen, P. and Komi, P. (1986) Segmental contribution to velocity of center of gravity during contact at different speeds in male and female sprinters. *Jounal of Human Movement Studies* **12,** 215-235.

Murphy, A.J., Lockie, R.G. and Coutts, A.J. (2003) Kinematic determinants of early acceleration in field sport athletes. *Journal of Sports Science and Medicine* **2,** 144-150.

Pinnington, H.C., Lloyd, D.G., Besier, T.F. and Dawson, B. (2005) Kinematic and electromyography analysis of submaximal differences running on a firm surface compared with soft, dry sand. *European Journal of Applied Physiology* **94,** 242-53.

Ross, S., Guskiewicz, K., Prentice, W., Schneider, R. and Yu, B. (2004) Comparison of biomechanical factors between the kicking and stance limbs. *Journal of Sports Rehabilitation* **13,** 135-150.

Schot, P.K. and Knutzen, K.M. (1992) A biomechanical analysis of four sprint start positions. *Research Quarterly for Exercise and Sport* **63,** 137-147.

SLSA (2005) Surf Life Saving Australia's High Performance Fitness Testing Protocols. Sydney, Surf Life Saving Australia Ltd.

Tellez, T. and Doolittle, D. (1984) Technique analysis: sprinting - from start to finish. *Track Technique* **88,** 2802-2805.

Vagenas, G. and Hoshizaki, T.B. (1986) Optimization of an asymmetrical motor skill: sprint start. *International Journal of Sport Biomechanics* **2,** 29-40.

Van Ingen Schenau, G.J., De Koning, J.J. and De Groot, G. (1994) Optimisation of sprinting performance in running, cycling and speed skating. *Sports Medicine* **17,** 259-275.

Vincent, W.J. (1995) *Statistics in Kinesiology,* Champaign, Human Kinetics.

Zamparo, P., Perini, R., Orizio, C., Sacher, M. and Ferretti, G. (1992) The energy cost of walking or running on sand. *European Journal of Applied Physiology* **65,** 183-187.

Key points

- There are specific movement patterns adopted by beach flags sprinters during the start. Sprinters will move posterior to the start time prior to turning. Following the turn, sprinters must position their feet such that force output is optimized and low body position at take-off can be attained.
- The body position at take-off from the beach flags start is similar to that of established technique parameters for track sprinters leaving starting blocks, and field sport athletes during acceleration. A greater range of motion at the arms can aid with stability during the turn and at take-off from the start. Greater knee extension of the drive leg at take-off can assist with reducing the duration of the start.
- The beach flags start must allow for a quick generation of speed through the initial stages of the sprint, as this can benefit the later stages. A longer first step following the start can help facilitate speed over the initial acceleration period. Beach flags sprinters must also attempt to maintain their speed throughout the entirety of the race.

AUTHORS BIOGRAPHY

Robert G. LOCKIE
Employment
Lecturer in Exercise and Sport Science, Univ. of Newcastle, Ourimbah, Australia.
Degree
PhD
Research interests
Biomechanics of acceleration and sprinting, strength and conditioning, speed, agility and power training
E-mail: robert.lockie@newcastle.edu.au

William M. VICKERY
Employment
PhD Candidate in Exercise and Sport Science, Univ. of Newcastle, Ourimbah, Australia.
Degree
Bachelor of Science (Hons)
Research interests
Physiological and physical demands of cricket players, small-sided games and intermittent training, GPS technology
E-mail: william.vickery@uon.edu.au

Xanne A.K. JANSE DE JONGE
Employment
Lecturer in Exercise and Sport Science, Univ. of Newcastle, Ourimbah, Australia.
Degree
PhD
Research interests
Athlete monitoring, effects of the menstrual cycle on exercise performance
E-mail: x.jansedejonge@newcastle.edu.au

✉ **Robert G. Lockie**
School of Environmental and Life Sciences, University of Newcastle, PO Box 127, Ourimbah, NSW, 2258, Australia